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THE UNDERFLOW IN ARKANSAS VALLEY IN WESTERN KANSAS

BY

CHARLES S. SLICHTER

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THE UNDERFLOW IN ARKANSAS VALLEY IN WESTERN KANSAS.

By Charles S. Slichter.

INTRODUCTION.

The investigation of the underflow of Arkansas River, described in this paper, was made during the summer of 1904. The field party was under the general supervision of the writer. Mr. Henry C. Wolff had charge of the measurements of the rate of movement of the ground waters. He also made careful determinations of the fluctuation of the position of the water plane, and the success of the field work was largely due to his skill and hard work. Mr. Ray Owen had charge of level and plane-table work, and made a contour map of the water plane.

A few of the principal conclusions may be summarized as follows:

1. The underflow of Arkansas River moves at an average rate of 8 feet per twenty-four hours, in the general direction of the valley.
2. The water plane slopes to the east at the rate of 7.5 feet per mile, and toward the river at the rate of 2 to 3 feet per mile.
3. The moving ground water extends several miles north from the river valley. No north or south limit was found.
4. The rate of movement is very uniform.
5. The underflow has its origin in the rainfall on the sand hills south of the river and on the bottom lands and plains north of the river.
6. The sand hills constitute an essential part of the catchment area.
7. The influence of the floods in the river upon the ground-water level does not extend one-half mile north or south of the channel.
8. A heavy rain contributes more water to the underflow than a flood.
9. On the sandy bottom lands 60 per cent of an ordinary rain reaches the water plane as a permanent contribution.
10. The amount of dissolved solids in the underflow grows less with the depth and with the distance from the river channel.

11. There is no appreciable run-off in the vicinity of Garden, Kans. Practically all of the drainage is underground through the thick deposits of gravels.

12. Carefully constructed wells in Arkansas Valley are capable of yielding very large amounts of water. Each square foot of percolating surface of the well strainers can be relied upon to yield more than 0.25 gallon of water per minute under 1 foot head.

13. There is no indication of a decrease in the underflow at Garden in the last five years. The city well showed the same specific capacity in 1904 that it had in 1899.

14. Private pumping plants in the bottom lands will be profitable for irrigation if proper kind of power be used. There should be a large field of usefulness for suction gas-producer power plants of from 20 to 100 horsepower, with Colorado hard coal or coke as fuel. Kansas crude oil in gas generators should prove profitable for use in the smaller plants. The present cost of pumping with gasoline for fuel is not encouraging.

CHAPTER I.

MEASUREMENTS OF THE UNDERFLOW OF ARKANSAS RIVER.

GENERAL STATEMENT.

Investigations of the underflow of Arkansas River were begun June 11, 1904. The work consisted of the mapping of the water plane or ground-water level within a distance of 6 to 12 miles from the river channel, and of observations by the electrical method of the rate of movement of the underflow. The ground-water levels were obtained by observing the water levels in private wells in the neighborhood of the river and in a few wells which were sunk especially for this purpose. The slope of the water plane was found to be between 7 and 8 feet to a mile in a general easterly direction, and from 2 to 3 feet to a mile toward the river channel from the country immediately to the north and south. The southern margin of the river valley is bordered for 5 to 10 miles to the south by sand hills, which are only partially covered with natural vegetation. These sand hills extend from east of Dodge, Kans., to beyond the Colorado line. The river valley proper varies in width from 1 to 5 miles. Near the river channel there is a strip known as "first bottoms," which is only a few feet above the river level. The principal cultivated portion of the valley lies from 3 to 8 feet higher than first bottoms, and is locally known as "second bottoms." North of the river valley the ground rises rather abruptly to the high plains with their well-known level topography and compact sod of native grasses. The slope of the water plane toward the channel of the river from the north is, as has been stated, about 2½ feet to a mile, but 10 to 14 miles to the north of the valley the slope of the water plane changes from southerly to northerly, and the land at the same time gently dips to the north toward the valley of White Woman Creek. The easterly slope of 7½ to 8 feet to the mile is maintained, however, quite constantly throughout all of this region. Fig. 1 shows the results of the determination of the water plane.

MEASUREMENTS 2 MILES WEST OF GARDEN, KANS. (CAMP 1).

The measurements showed a rate of movement much greater than had been anticipated. The first set of underflow stations were established at a point about 2 miles west of Garden (camp 1), as shown on the map (fig. 1). The stations were in a north-south line, which was

about 1½ miles in length. At this point the river flows in an east by south direction, and borders closely on the north margin of the sand

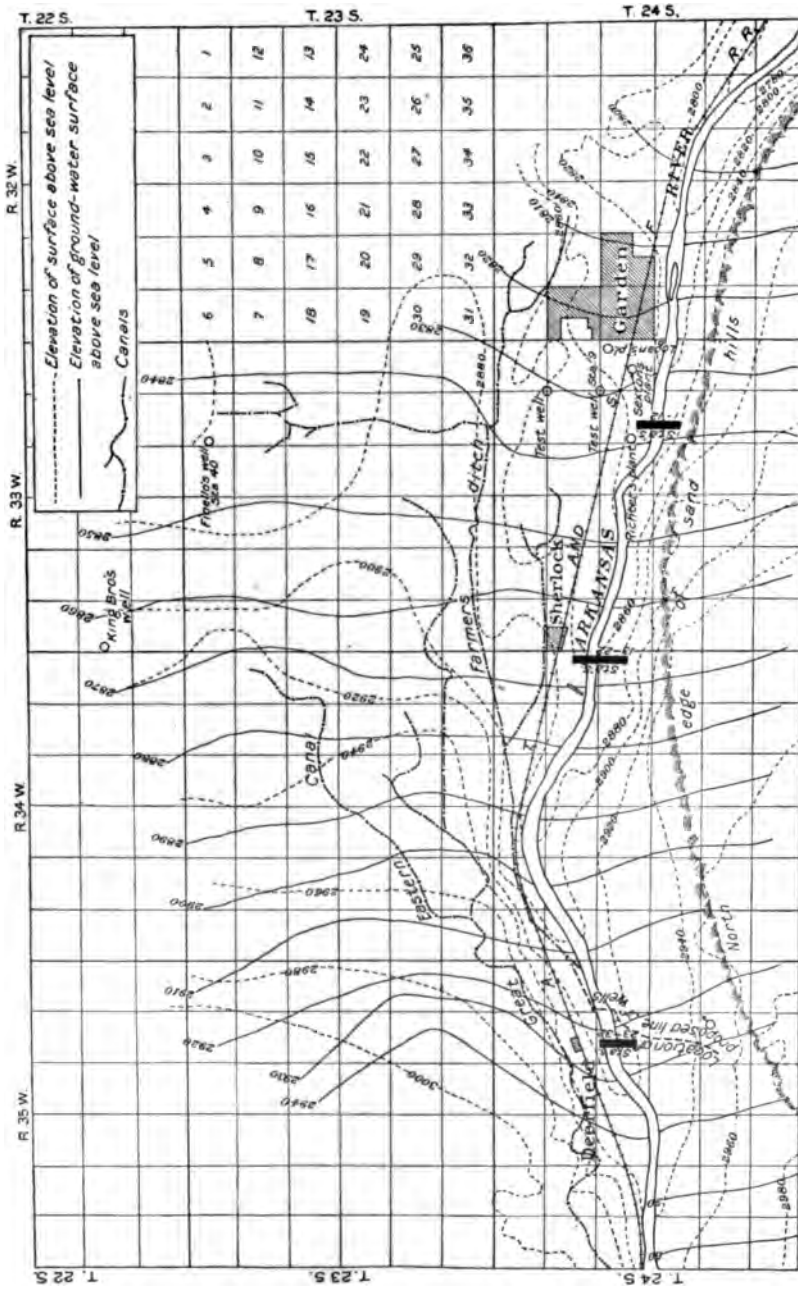
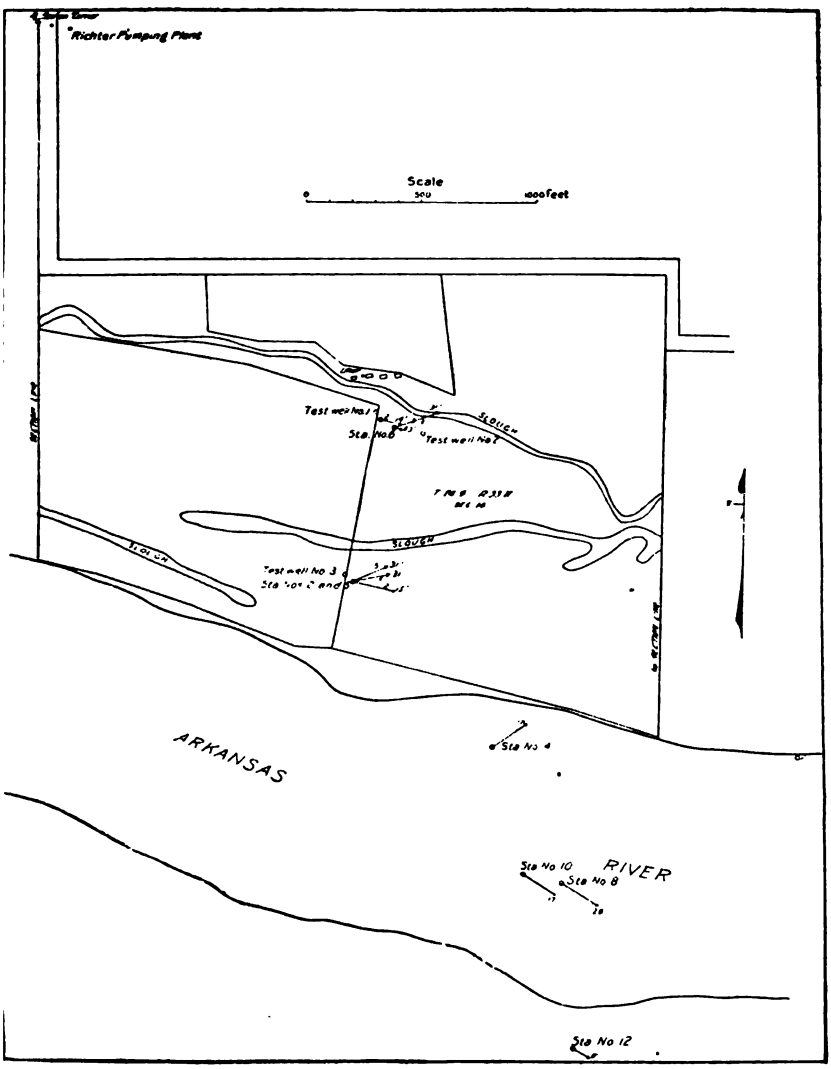


FIG. 1.—Map showing the water plane or ground-water surface between Garden and Deerfield, Kans., as determined during the summer of 1904. Underflow stations shown west of Garden, and near Sherlock and Deerfield, Kans.

hills, leaving but little bottom land on the south side of the river. The channel of the river where the observations were made is about 1,000 feet wide. On the north side is a strip of low land, or first bottoms,

bout 1,100 feet wide, which is only a few inches above the general ottom of the river bed. This low bottom has several sloughs runing through it approximately parallel to the river. North of this ow strip of bottom the land abruptly rises several feet and continues



ig. 2.—Map showing location of underflow stations and test wells at camp 1, 2 miles west of Garden, Kans. The velocity and direction of flow is shown by the length and direction of the arrows at the various stations. The depth is indicated in figures at each location.

o rise gradually for several miles farther north, this slope constituting the cultivated portion of the valley—the so-called second bottoms.

The measurements at this point were made at stations that lay, in general, in a straight line across the valley (fig. 2). Most of the measurements were made in the river channel itself, or on the low ground

to the north. One test was made on the south side of the river at the foot of the sand hills and another 1 mile to the north. The velocities were determined at depths ranging from 11 to 65 feet. The results of the measurements at this location are given in Table 1.

TABLE 1.—*Underflow measurements at camp 1, 2 miles west of Garden, Kans.*

Date of test.	No. of station.	Depth of well.	Velocity of ground water.	Direction of flow, east of north.	Location and remarks.
1904.		*Feet.*	*Ft. per day.*	°	
June 30	9	16	5.3	90	1 mile north of river.
June 22	1	14	4.8	101	1,100 feet north of river.
Do	3	31	10.3	71	Do.
June 21	2	15	9.6	103	430 feet north of river.
June 24	5	31	8.0	65	Do.
June 26	5	29	8.0	77	Do.
June 25	4	17	9.0	55	In channel, 250 feet north of center.
July 6	8	28	9.6	121	In channel, 150 feet south of center.
July 4	10	17	8.2	121	Do.
July 9	12	11	4.0	120	250 feet south of river.
September 6	6	65	1.75	101	1,100 feet north of river.
September 8	40	25	1.3	104	NW. corner SW. ¼ sec. 2, T. 23 S., R. 33 W., 8½ miles north of river.
Average			6.6	94	

Mean direction of river channel, 100° east of north.

Of the stations for which data are given in this table, No. 9 was located on the second bottoms 1 mile north of the river, No. 40 was located on the uplands 8½ miles north of the river, and No. 12 was in the sand hills south of the river. The other stations were either in the first bottoms or in the channel. Station No. 6 reached so-called "second water," or the water beneath a layer of silt which seemed quite impervious to the flow of water. The mean of all of the observed velocities was 6.6 feet a day. The average direction of the motion was 94° east of north, which may be compared to the average direction of the river valley at this point, which we have estimated to be approximately 100° east of north. On the cross section through the river channel and the first bottoms (fig. 3) are shown the depth of a number of the test wells near the river channel and the velocity of the underflow.

Except for occasional layers of silt, the gravels were very uniform in size and character of grain; a large percentage of any one sample consisted of grains larger than grains of wheat. The gravel was also found to be very uniform in lateral extent, but showed a tendency to become coarser with the depth until 32 feet was reached. At about 32 feet fine sand and silt was encountered, which seemed, as nearly as could be determined from the wells sunk in a comparatively small radius, to be horizontal in extent. Fine material was encountered at a higher level at only one place, which was near the center of the river at a depth of about 18 feet, but 50 feet upstream it was entirely absent.

A well was put down at station No. 11 in order to secure a sample of this fine material. It was found at the same level as at stations No. 6 and No. 8, and consisted of about the same kind of material, except that it contained a considerable amount of gypsum mixed with sand. This fine sand must be more or less impervious, for no water could be drawn by means of a hand pump from a well driven in the sand, and a hole washed out 8 feet below the casing remained for a considerable time unfilled with sand.

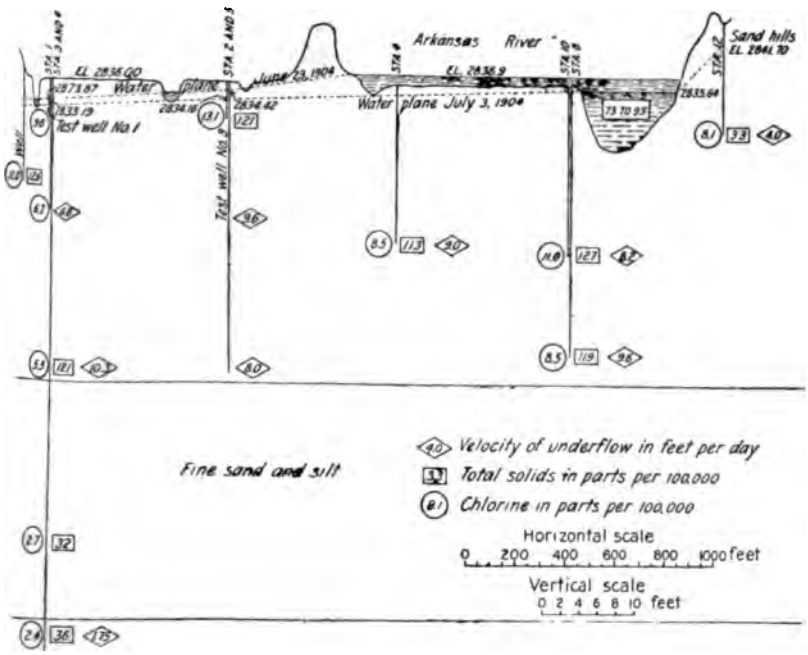


FIG. 3.—Cross section near camp 1, 2 miles west of Garden, Kans. The total solids dissolved in the ground water at various depths are shown, in parts per 100,000, by the numbers inclosed in rectangles. The numbers inclosed in circles express the amount, in parts per 100,000, of chlorine found at the position at which the circles are placed.

The velocities above this layer of silt are very uniform, ranging from 4.8 feet a day to 10.3 feet a day, with an average for ten tests of 7.68 feet a day, with the direction varying from 55° east of north to 121° east of north.

The direction of motion at these various stations, as has been stated, was in general toward the east, but several exceptions were noted from time to time. At the time field work was begun the channel of the Arkansas River was dry, as is very usual in the months from June to October. The summer of 1904, however, proved to be an exceptional one, and high floods were of constant occurrence throughout the season. One of these floods came down the river soon after the first underflow stations were established near the bank of the river. This offered an excellent opportunity of determining the influence of the

river waters upon the underflow. At one underflow station, situated near the north bank of the channel of the river, 2 miles west of Garden, the direction of the flow of the ground waters was very greatly changed by the flood in the river. It was therefore possible to measure the rate at which the river contributed to the ground waters at this point. It was found that the water during the early stages of the flood flowed away from the river at the rate of 6 to 8 feet per twenty-four hours. This point can be established by consulting the record for stations No. 2 and No. 5, as given in Table 1. These stations are located at the same point. The velocity at station No. 2 on June 21, 1904, before a rain on the night of June 21, and before a flood which came down the river at 3 p. m. June 22, was 9.6 feet per twenty-four hours in a direction 103° east of north, which is substantially the direction of the river channel. After the flood the velocity at the same place (at a greater depth, however) was found to be 8 feet per twenty-four hours, in a direction 65° east of north, or at an angle of 35° away from the river channel, the flood having therefore changed the former direction of flow by about 38°. On June 26, when the flood had still further receded, a second determination of velocity showed the same rate as before, but the direction had shifted to 77° east of north, or at an angle of about 23° with the river channel.

It was not only possible to actually determine this rate of loss of water from the river by the use of the electric underflow meter, but the northerly progress of the water from the river into the gravels could be noted by observation of the changes in the temperature of the ground water as it flowed north. The river water was much warmer than the natural ground water, and the increased temperature could be followed away from the river bank. These facts are shown by the temperatures of the water recorded in Table 11. In that table will be found the following entries:

Temperature of water of river and test wells, June 20, 1904.

	°F.
River	71
Test well No. 3, 360 feet north of river	62.5
Test well No. 1, 1,100 feet north of river	59

The water taken from the other wells had a somewhat more uniform temperature, excepting in two cases—that taken from the wells at station No. 10 and station No. 8. At station No. 10, at a depth of 18 feet, the temperature was 51°; at station No. 8, 28 feet below the bottom of the river, the temperature was 48°, which was the coldest water found at any point. At these two stations the direction of the underflow was the most southerly of any found, being in each case 121° east of north.

It was also possible to partially trace inward moving ground water originating in the river by the change in the chemical composition of the water. Apparatus was at hand for determining the alkalinity,

hardness, chlorine, and the total solids dissolved in the water; and this apparatus was used to secure the results just stated. A further verification of the inwardly moving ground water was found in the changed slope of the water plane during the flood periods in the river. The water plane sloped away from the river about 8 feet to the mile during the first stages of high water, and corresponded quite accurately with the observed velocities of the water. Fig. 3 shows the slope of the water plane on June 23 and July 3. Several gradients corresponding to other dates are given in Table 1.

MEASUREMENTS AT SHERLOCK, KANS. (CAMP 2).

Several underflow measurements were taken at camp 2, which was situated at Sherlock, Kans., 7 miles west of Garden. The results differed little from those found at the first set of stations at camp 1, except that more sorting of the gravels had taken place at the latter point, giving greater variety to the rate of movement. The location of the various test wells and underflow stations is marked in fig. 4. The same stations are shown in cross section in fig. 5. The details of the results are printed in Table 2. From this table it will be observed that the average velocity of the underflow for all of the stations was 8.9 feet per twenty-four hours. The mean direction of the motion was 93.5° east of north, which may be compared with the mean direction of the river valley at this point, which was computed to be 105° east of north. There was some water in the river throughout all of the time during which the tests were made, and on July 27 a heavy flood swept down the river.

TABLE 2.—*Underflow measurements at camp 2, Sherlock, Kans.*

Date of test.	No. of station.	Depth of wells.	Velocity of ground water.	Direction of flow, east of north.	Location and remarks.
1904.		*Feet.*	*Ft. per day.*	°	
July 16	13	18	5.7	64.0	700 feet north of river.
July 30	21	28	22.9	64.0	Do.
July 31	22	28	2.8	101.0	1,700 feet north of river.
July 17	14	22	9.1	75.0	In channel, 500 feet north of center.
July 23	18	21	16.0	101.0	In channel, 20 feet north of center.
July 22	17	36	3.0	103.0	In channel, 210 feet south of center.
July 18	15	22	16.7	132.0	Do.
July 29	20	26	2.2	122.0	200 feet south of river.
July 22	16	18	2.0	79.0	2,100 feet south of river.
Average			8.9	93.5	

Mean direction of river channel, 105° east of north.

By studying the results of the measurements it will be observed that station No. 22 was on the border of the second bottoms, 1,700 feet north of the north bank of the river. The velocity at this station was 2.8 feet per day, and the direction of flow was substantially

the same as the direction of the river valley. This result is imp tant, as the measurement was made on July 31, at a time when t

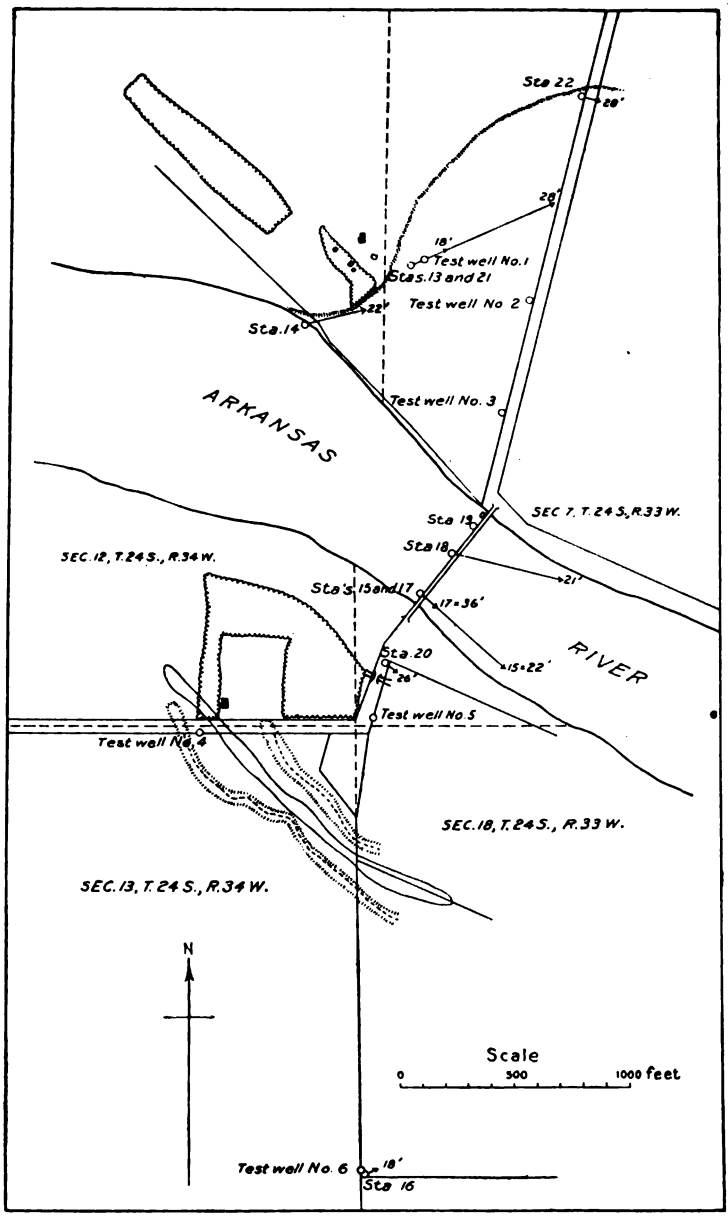
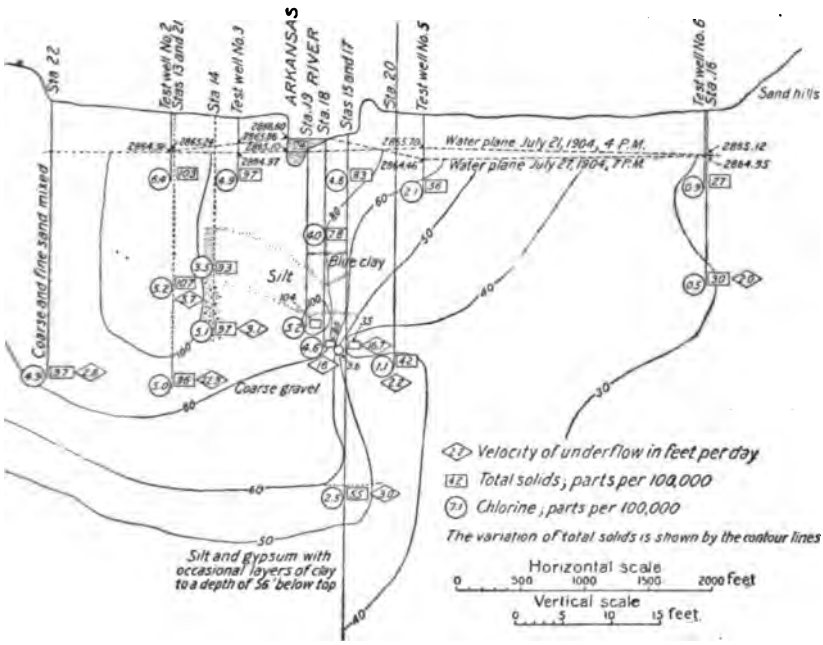


FIG. 4.—Map showing location of underflow stations and test wells at Sherlock, Kans., 7 miles we Garden. The velocity and direction of flow of the ground water are shown by the length and d tion of the arrows at the various stations. The depth is indicated in figures at each station.

flood of July 27 should have shown some influence upon the direct of flow, if it had any at all. The direction of motion at this stat was in marked contrast to the direction of flow observed at stati

o. 13 and No. 21, located in the first bottoms, 700 feet north of the ver. At both of the latter stations the direction of flow was 64° ıst of north, or in a direction making an angle of 41° northeast of ıe general direction of the river valley. These stations were within ıe immediate influence of the fluctuations of the height of the water ı the river.[a]

Of the stations established in the channel of the river itself, it is ıteresting to note that a station located north of the center of the



ı. 5.—Cross section at camp 2, near Sherlock, Kans. The total solids dissolved in the ground water ıt various depths are shown in parts per 100,000 by the numbers inclosed in rectangles. The ıumbers inclosed in circles express the amount, in parts per 100,000, of chlorine found at the position where the circles are placed. The contour lines show the position of water of the same strength. The contribution of soft water from the sand hills is very apparent.

hannel (station 18) showed a component of velocity northerly to the general trend of the valley, while a station south of the channel (station 15) showed a component of velocity southerly to the direction of the valley. At station No. 17, in the channel at the same point as station No. 15, but at a greater depth, the direction of the flow corresponded closely with the direction of the valley, indicating that the influence of flowing water in the river did not extend so deep. Station No. 20 was located on the first bottoms, 200 feet south of the south bank of the river. The motion at this point showed a southerly component, the direction of flow making an angle of 17° with the direction of the valley. The measurement was taken while the river was in

[a] This fact will be further illustrated at a later place in this report.

flood. Station No. 16 was located in the border of the sand hill nearly a half mile south of the river. The direction of flow was towa the river and away from the sand hills, as should be expected account of the excellent collecting area offered by the sand hills to t rainfall.

The fact that the influence of the river only extends to very shallo depths and that a considerable portion of the ground water orig nates in the sand hills is shown by the cross section (fig. 5). The co tour lines in this figure correspond to equal amounts of total soli dissolved in the ground water. The soft water from the sand hills c be observed to be crowding the strong water of the underflow to t north of the valley.

MEASUREMENTS AT DEERFIELD, KANS. (CAMP 3).

Camp 3 was established near the Deerfield bridge, 14 miles west Garden. The valley at this point lies mostly south of the chann All of the south-side lands, to the edge of the sand hills, would prob bly be classed as "first bottoms." The surface of the ground on the lands is only a few feet above the river bed and the soil is unusual sandy. The topography of the sand hills south of the bottom lands unusually well adapted for collecting the rainfall, there being seve level stretches inclosed or hemmed in by the hills. A short distan south of station No. 23 there are found the remains of a former riv bank, indicating that an ancient channel extended as far south as st tion No. 23 (see fig. 6).

On the north side of the channel the river sweeps a high bank fro 6 to 10 feet above the river bed for a distance of about 3 miles. T uplands begin not more than 1 mile north of the river.

Since the channel here borders the extreme north margin of t valley the underflow measurements were made south of the river in the channel. The results are printed in Table 3.

TABLE 3.—*Underflow measurements at camp 3, Deerfield, Kans.*

Date of test.	No. of station.	Depth of wells.	Velocity of ground water.	Direction of flow east of north.	Location and remarks.
1904.		*Feet.*	*Ft. per day.*[a]	°	
August 6	25	16	6.3	66.0	In channel at center.
Do	24	21	12.5	67.0	In channel 400 feet south of center
August 5	23	24	19.2	111.0	500 feet south of river.
August 8	26	36	9.2	111.0	Do.
August 9	27	24	14.8	129.0	1,050 feet south of river
August 12	28	21	1.25	74.0	1,800 feet south of river.
September 22	29	17	1.6	56.0	1.8 miles south of river.
August 17	32	31	2.2	63.0	1,800 feet south of river.
Average			8.4	84.6	

[a] Mean direction of river channel, 70° east of north.

The average velocity of the ground water, 8.4 feet per twenty-four hours, compares accurately with the average velocities found for stations similarly located at previous camps. The mean direction does not correspond as accurately with the general trend of the river

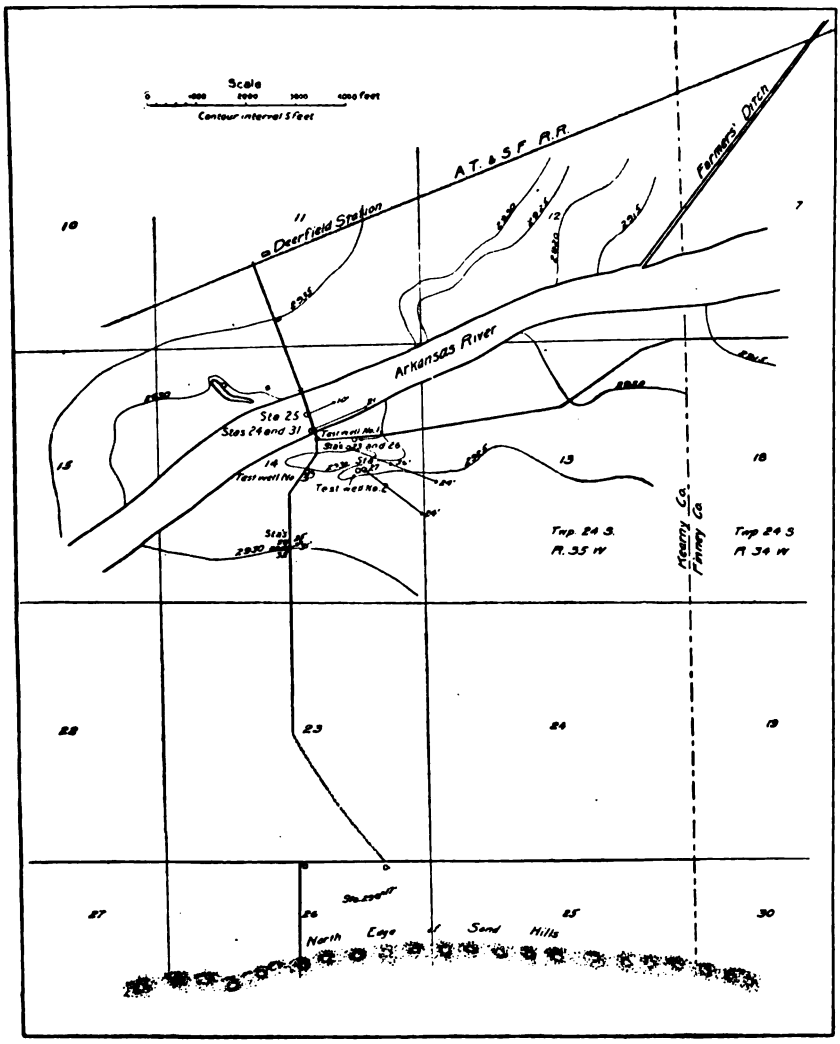


FIG. 6.—Map showing the location of underflow stations at camp 3, near Deerfield, Kans. The velocity and direction of flow of the ground water is shown by the length and direction of the arrows. The depth is indicated in figures at each station.

channel as at other stations, probably in part owing to the fact that the river has at this point a very northerly course.

It will be observed that the direction of flow at stations Nos. 23, 26, and 27, which are, respectively, 500, 500, and 1,050 feet south of the river, had a strong southerly component, the resultant direction of

This result was somewhat surprising, so that a second line of levels was run to the river along the east line of section 13 until this line intersected the river. This line of levels intersected the river at a point three-fourths of a mile below the former point. The river at this point was found to be 3 feet higher than the surface of Clear Lake. Since the river slopes about 7½ feet to the mile, this checks the former measurement that the river opposite the pond is 8 feet higher than the water in the latter.

The above observations seem to indicate that the small pond known as Clear Lake is one of the many circular depressions which are found throughout the western plains, and which have been fully described by Mr. Willard D. Johnson.[a]

This small pond is of especial interest because it is in line with the dry channel of a plains stream called Bear Creek. This stream rises in Colorado, and near the western border of Kansas has a well-marked valley, eroded to a depth of nearly 100 feet, but as it approaches Arkansas River, near the north edge of Grant County, it loses this and its waters spread out on the plains and sink. The ordinary flow of this stream is very small, but during times of heavy rain in eastern Colorado and western Kansas it may carry a large quantity of water, which it pours out upon the high plains of northern Grant County and into the sand hills along the south side of Arkansas River. On some occasions the freshets in this stream have been so severe that the waters have nearly reached the Arkansas. There is a slight elongated depression extending through the sand hills in line with Clear Lake which makes it possible to believe that the waters of Bear Creek have on some occasions in the past extended to the Arkansas, but so far as known there is no settler who can testify to having actually observed such an event.

It can easily be believed, from the rather remarkable character of Bear Creek, that settlers would naturally associate Clear Lake with the disappearing waters of Bear Creek, so that the story would become current that Clear Lake was merely an evidence or indication of the existence of an underground stream extending from the sand hills to Arkansas Valley itself. On this account belief in the adaptability of the lake for a supply of a large quantity of water for irrigation has been prevalent, so that an investigation of the conditions surrounding the lake has importance. There are several streams of the same type as Bear Creek in western Kansas.

Underflow stations Nos. 33, 35, and 36 were established, as shown on the map (fig. 7), for the purpose of determining the direction and magnitude of the velocity of the underground water. It was hoped to determine in this way whether or not there was any seepage at this point from the direction of Bear Creek toward Arkansas Valley. The

[a] The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1900, pp. 609, 693–715.

pipe 75 feet of wash pipe was used, so that samples were washed up from a depth of about 12 feet below the bottom of the 2-inch well. The material washed out consisted of black mud and clay, with some quicksand.

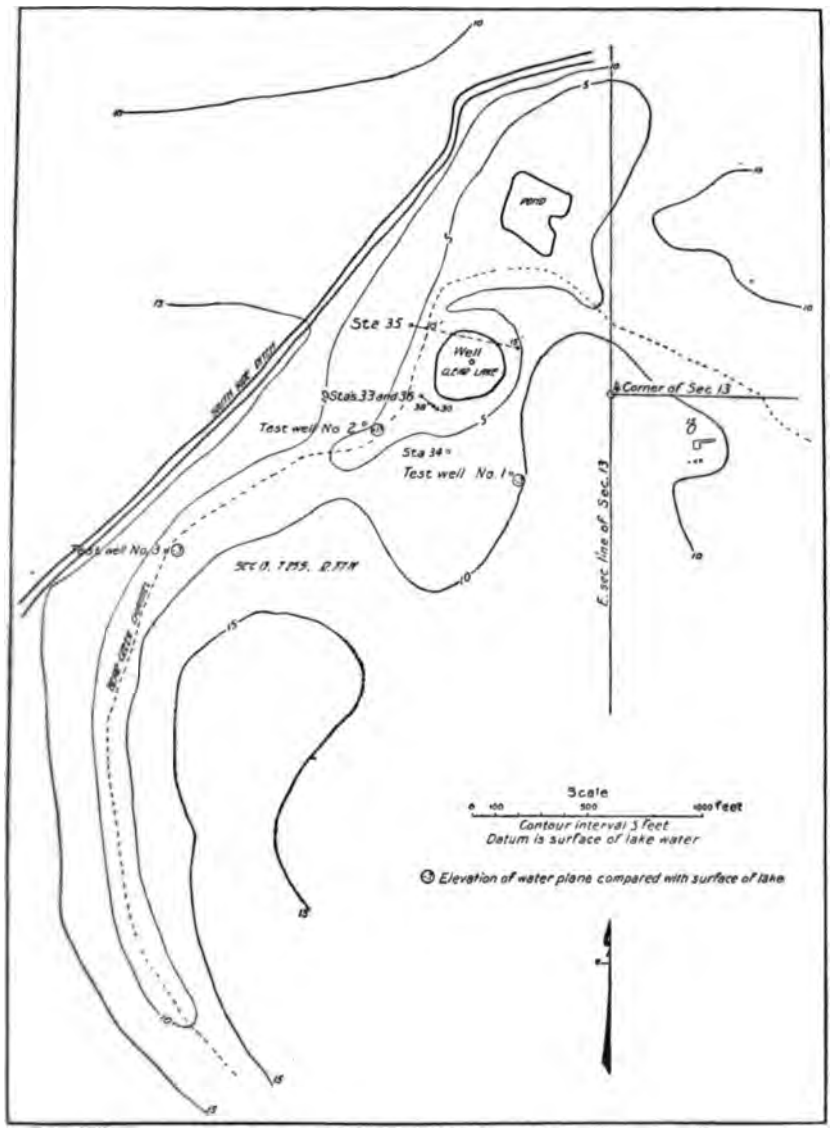


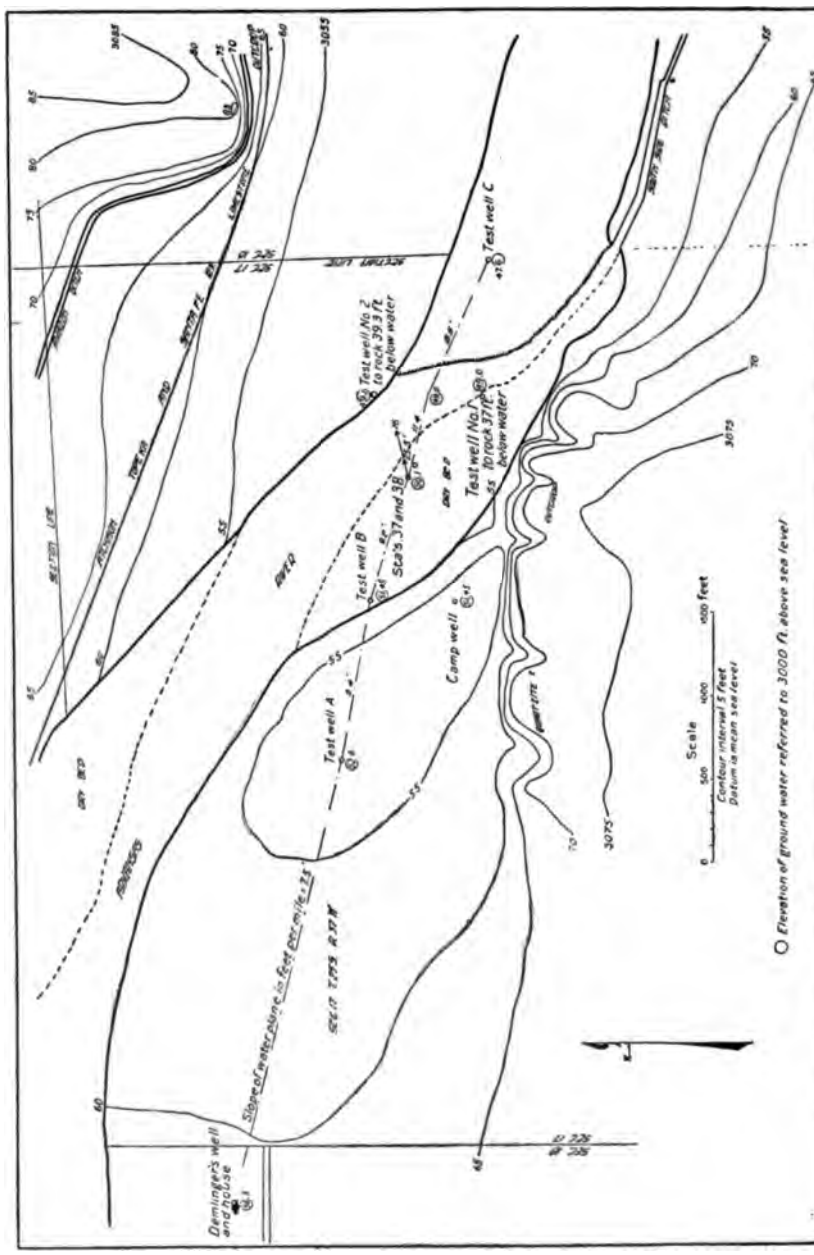
FIG. 7.—Map showing location of underflow stations and test wells near Clear Lake, Kansas.

A line of levels was run from Clear Lake to Arkansas River as nearly as practicable at right angles to the direction of the river channel. The result of this leveling showed that the river was at least 8 feet higher than the lake.[a]

[a] Field notes show that the river was quite high at the time of the observation on August 20, 1904.

MEASUREMENTS OF THE UNDERFLOW AT THE NARROWS ON ARKANSAS RIVER, NEAR HARTLAND, KANS. (CAMP 5).

Two miles west of Hartland, Kans., Arkansas River flows between rock bluffs, the distance between which at the narrowest portion is



2,250 feet. The river channel occupies 900 feet of this distance, only a portion of which was utilized by flowing water on August 24, 1904.

wells A, B, and C were driven to shallow depths for th
f determining the slope of the water plane through the Nar

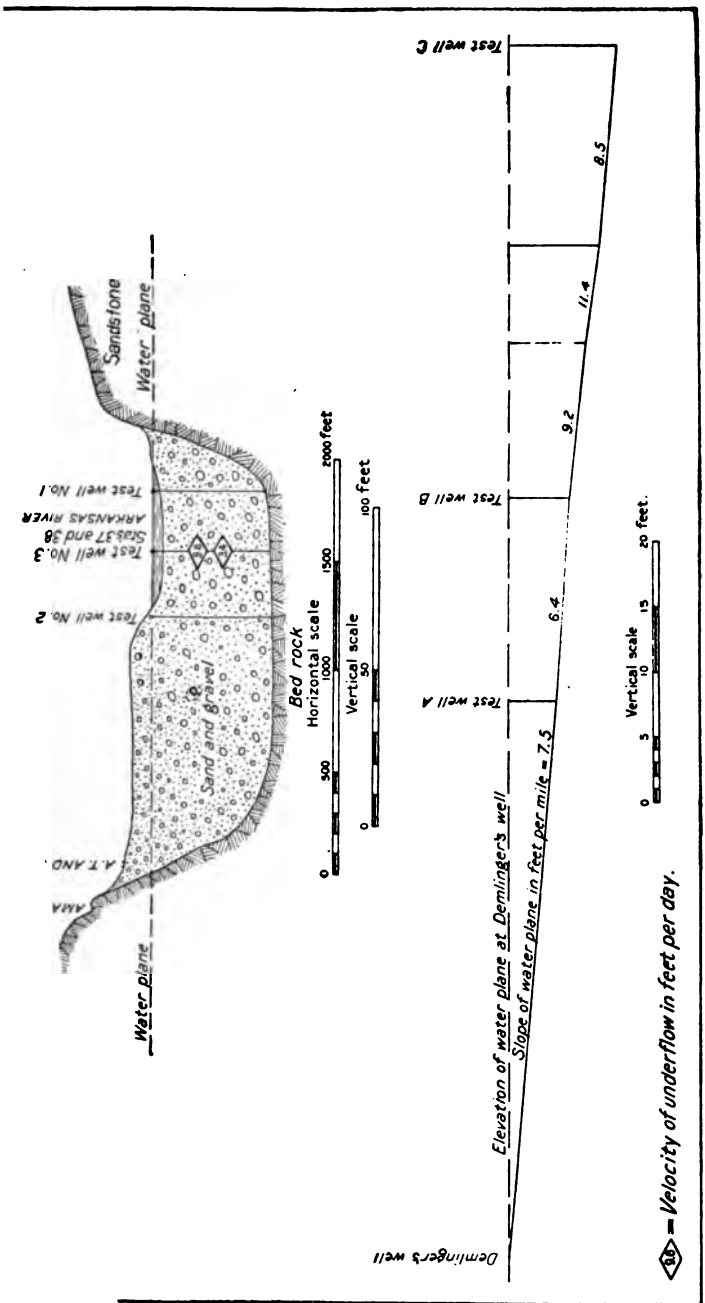


FIG. 9.—Cross section at the Narrows of Arkansas River, west of Hartland, Kans. The slope of the water plane through the Narrows is shown b
line at the bottom of the drawing.

hese test wells, the elevation of the water was taken
ell and in the wells of station No. 38, and in test wells

driven for the purpose of testing for rock. These wells form a line about a mile long, as indicated on the map (fig. 8). The gradient of the water plane in the first portion of this line was 7.5 feet per mile; in the next portion it was 6.4 feet per mile, and in the next 9.2 feet per mile. Just above the Narrows the gradient was found to be 11.4 feet per mile, and in the last portion, in the Narrows itself, the slope of the water plane was 8.5 feet per mile. A profile showing these gradients is given at the bottom of fig. 9.

Test wells Nos. 1 and 2 (shown in fig. 8) were driven for the purpose of testing for bed rock. What is believed to be rock was struck at test well No. 1, at elevation 3,011.7, or 37 feet below the water plane, and at test well No. 2 rock was reached at elevation 3,009.8, or 39.3 feet below the water plane. Rock was also struck at station No. 38 at 38.75 feet below the water plane. As a diamond drill was not at hand, the evidence that bed rock was reached is, of course, not conclusive. The only test that could be applied was the evidence supplied by the drill on the wash pipe and by the way in which the 2-inch casing acted when an attempt was made to drive it.

Two measurements were made of the rate of movement of the underflow near the center of the Narrows at stations Nos. 37 and 38. The velocities determined were 9.6 feet per twenty-four hours at a depth of 16 feet and 3.4 feet per twenty-four hours at a depth of 25 feet.

TABLE 5.—*Underflow measurements at camp 5, Narrows of Arkansas River, near Hartland, Kans.*

Date of test.	No. of station.	Depth of wells.	Velocity of ground water.	Direction of flow, east of north.	Location and remarks.
1904.		*Feet.*	*Ft. per day.*	°	
August 23	37	16	9.6	77	Center of channel.
August 26	38	25	3.4	77	Do.

From the cross section of the Narrows (shown in fig. 9) an estimate can be made of the amount of water which flows through the Narrows. The total cross section of the sands, assuming the above test borings as indicating the true position of bed rock, is 75,000 square feet. Assuming one-third as the porosity of the sands and 10 feet per day as the average velocity of the ground water, the total flow through the Narrows would be 250,000 cubic feet per day, or 2.9 cubic feet per second. The actual average velocity of the underflow is undoubtedly much less than 10 feet per day, so that the above result represents the maximum that can be claimed in a high estimate.

CHAPTER II.

FLUCTUATIONS OF GROUND-WATER LEVEL.

:NFLUENCE OF RAINFALL AND OF HEIGHT OF WATER IN ARKANSAS RIVER ON THE GROUND-WATER LEVEL.

uring the field work of the summer several opportunities were ıd to observe the influence of a change of level of the water in the r upon the water plane in the adjacent bottom lands. The summer 904 was especially favorable for observations of this kind, as the on was an exceptional one, both in respect to the rainfall and as to ıuantity of water flowing in the river. There was water in Arkansas ɜr, in western Kansas, during nearly all of the time from the mid- ɔf June to the middle of September, and on several occasions floods ıarked suddenness and great severity passed down the river. The fall during the same period was above the average. The record ıinfall from May 1 to October 1, as observed by the volunteer sta- of the United States Weather Bureau at Garden, Kans., is given able 6.

TABLE 6.—*Daily precipitation, Garden, Kans., May 1 to September 30, 1904.*

Date.	May.	June.	July.	August.	September.
.....	0.58	0.0	0.0	0.03	0.0
.....	Trace.	.25	.0	.0	.24
.....	1.82	.04	.0	.0	.0
.....	.75	.0	.95	.28	.0
.....	.0	.0	Trace.	.0	.0
.....	.0	.0	.12	.45	.0
.....	.0	.0	.55	.0	.0
.....	.20	.0	1.10	.0	.0
.....	.0	.72	.0	Trace.	.0
.....	.0	.0	.05	.0	.0
.....	.0	.0	.0	.0	.0
.....	Trace.	.0	1.32	.0	.0
.....	.0	.30	.08	.0	.0
.....	.0	.0	.0	.0	.0
.....	Trace.	.0	.0	.0	.0
.....	.0	Trace.	.0	.0	.0
.....	.0	.19	.0	.0	.0
.....	.0	.0	.0	.04	.0
.....	.0	.0	.0	.32	.0
.....	.0	.0	Trace.	.0	.0
.....	.03	Trace.	Trace.	.0	.0
.....	.85	.94	[a] 1.42	.0	.0
.....	.0	.0	.0	.0	.0
.....	.0	.0	.0	.0	.0
.....	.0	.0	.06	.11	.0
.....	.0	.0	.0	.0	.0

[a] Much less at Sherlock, Kans.

TABLE 6.—*Daily precipitation, Garden, Kans., May 1 to September 30, 1904*—Continued.

Date.	May.	June.	July.	August.	September.
27	0.03	0.0	0.0	0.0	0.10
28	.04	.20	.0	.0	1.85
29	.0	.0	.0	.0	1.10
30	.0	.0	.0	.09	.10
31	.0	.....	Trace.	Trace.	.....
Total	4.30	2.64	5.65	1.32	3.39

Total for five months, 17.30.

Observations of the water plane were made very systematically during the various stages of the water in the river by Mr. Wolff, who was in charge of the party making the field observations. The results of these observations are given in the accompanying diagrams, which Mr. Wolff has constructed from the field notes. The first underflow determinations were made at the camp located about 2 miles west of Garden, Kans., on the ranch of Mrs. M. Richter, which is referred to in the text as camp 1. At this camp a number of shallow test wells were put in place for the special purpose of observing the position of the water plane. These test wells are shown on the map (fig. 2), from which it will be observed that test wells Nos. 1 and 2 were located north of the river bank at a distance of about 1,070 feet; test well No. 3 was closer to the river, at a distance of about 360 feet from the north bank. A large well located on the ranch of Mrs. Richter, and used for irrigation, was also used for the purpose of keeping track of the fluctuations of the water plane. The location of this well is shown on the map (fig. 2) near the quarter-section corner in the upper right-hand corner of the map. As will be observed, this well is situated a considerable distance upstream from test wells Nos. 1, 2, and 3; hence the water in it stood much higher than that in the test wells, since the water plane slopes eastward at the rate of about 7½ feet per mile. The land in which test wells Nos. 1, 2, and 3 are situated is what is commonly called in that locality "first bottoms." Immediately north of test wells Nos. 1 and 2 the "second bottoms" begin, the land here being some 3 to 5 feet higher than in the "first bottoms." Two sloughs shown on the map were grass covered, but contained more or less water either during high stages of the river or after heavy rains. In fig. 10 the elevations of water in Arkansas River from June 16 to July 11, 1904, and the elevations in test wells Nos. 1, 2, and 3 and in Mrs. Richter's well are represented graphically. The elevations are expressed in feet above mean sea level, as determined from the United States Geological Survey permanent bench marks in the valley. The detailed observations at these stations are printed in Table 7, in which the elevations are given in feet above mean sea level. The observation of the height of the river was made from a gage rod set up in the river and observed from the bank with

a level. Observations were made morning and evening during the period covered by the table. There were occasional omissions of observation of river height, due to the absence of the level from camp.

TABLE 7.—*Elevation of ground water in the Arkansas River and in test wells near camp 1, 2 miles west of Garden, Kans.*

[Wells Nos. 1 and 2 are 1,070 feet north of river; well No. 3 is 360 feet north of river. Datum is 2,800 feet above mean sea level.]

Date.	Time.	Elevation of water in well No. 1.	Hydraulic gradient per mile from well No. 2 to well No. 1.	Elevation of water in well No. 2.	Hydraulic gradient per mile from well No. 1 to well No. 3.	Elevation of water in well No. 3.	Elevation of water in river.	Barometric pressure in inches of mercury.
1904.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Inches.*
June 16	12 m	33.97					36.7	28.60
Do	6 p. m	33.86						26.54
June 17	6 a. m	33.90						26.62
Do	12 m	33.87						26.55
Do	6 p. m							
June 18	6 a. m	33.98						26.63
Do	6 p. m	33.76	6.4	33.53	6.3	34.61	36.2	26.50
June 19	6 p. m	33.75	4.7	33.58	5.9	34.55		26.45
June 20	6 a. m	33.89	8.1	33.60	5.3	34.61	36.1	
Do	6 p. m					34.41	36.0	
June 21	6 a. m	33.82			4.8	34.47	36.0	26.47
Do	12 m	33.59	6.4	33.36	5.5	34.33		
Do	6 p. m	33.77	7.2	33.51	4.5	34.38		
June 22	6 a. m	34.45	8.9	34.13	4.2	35.02		
Do	12 m							
Do	6 p. m	33.94			8.8	35.12	37.7	
June 23	6 a. m	34.05	6.7	33.81	7.6	35.07	36.9	26.27
Do	6 p. m	33.87			8.0	34.95	36.9	
June 24	6 a. m	34.00	6.9	33.75	7.1	34.95	36.5	
Do	6 p. m	33.77	6.7	33.53	6.8	34.69	36.3	26.35
June 25	6 a. m	33.93	8.1	33.64	5.1	34.61	36.2	
June 26	6 a. m	33.93			3.6	34.42	35.9	
Do	12 m	33.77	6.1	33.55				
June 27	6 a. m	33.93	7.7	33.67	3.9	34.45	35.9	
Do	6 p. m						35.9	
June 28	6 p. m						35.9	
June 29	6 a. m						35.8	
Do	6 p. m						35.8	
July 1	6 a. m						35.7	
Do	6 p. m						35.7	
July 2	6 a. m						35.7	
Do	6 p. m						35.7	
July 3	6 a. m						35.7	
Do	6 p. m	33.19	6.7	32.95	7.2	34.16	35.6	
July 4	6 a. m						35.6	
July 5	6 a. m						35.6	
July 6	6 a. m						35.6	
July 7	6 a. m	33.99	7.2	33.73	2.72	34.35	35.6	
Do	6 p. m						35.6	
July 8	6 a. m	34.53	7.2	34.27	3.64	35.02	35.7	
July 9	6 a. m	33.88	8.1	33.59	1.71	34.11	35.7	
July 10	6 a. m						35.6	
July 11	6 a. m	33.68	8.1	33.39	3.15	34.10	35.8	

From the morning of June 21 until noon of June 22, which are left blank in the table, there was no material change in the height of the river. The water in the river slowly sank during the period covered from noon of June 16 to noon of June 22. The record shown in fig. 10 begins on June 16. The levels in the various wells remained substantially stationary from that date until June 22. During the night of June 21 a heavy rain fell, which is given on the official record at Garden as 0.94 of an inch. The test wells on the morning of June 22 showed marked changes in the elevation of the ground water, due to the rain of the previous night. Well No. 1 rose 0.68 of a foot; well No. 2 rose 0.62 of a foot; well No. 3 rose 0.64 of a foot, while the Richter well rose 0.05 of a foot before noon of June 22, and by the morning of June 24 had risen 0.10 of a foot. The river remained stationary until 3 p. m. of June 22, when a flood consisting of an abrupt wave swept down the river, causing a rise of 1.7 feet. Notwithstanding this rise in the river, the water in test wells Nos. 1 and 2, 1,070 feet from the river, fell during the interval between the morning and evening of June 22, while test well No. 3, which was situated within 360 feet of the river bank, was only 0.1 higher at 6 p. m. of June 22 than it was at 6 a. m. on the same day. These results show that the heavy rain of the night of June 21 raised the water in all of the test wells, but that the flood of the afternoon of June 22 raised the water only in the well nearest the river. The river gradually receded from the high-water mark reached on the afternoon of June 22, and all of the test wells gradually fell. There was no rain until July 4, except a slight shower on June 28. Test wells Nos. 1, 2, and 3 showed a tendency to fall, although the water in the river was from 2 to 3 feet higher than the water in the wells during all of this period.

The rise in the water plane from 6 p. m. of June 21 to 6 a. m. of June 22, amounting to a rise of 0.68 foot in test well No. 1 and 0.62 foot in test well No. 2, was due, as stated above, to a heavy rain which fell during the night. From the data at hand it is possible to express the magnitude of the contribution to the underflow as so many cubic feet of water for each mile of the river valley. If this contribution be supposed to extend uniformly over a given period of time, then the addition to the ground water may be expressed as a continuous flow of so many cubic feet of water per second for each linear mile of the river valley. Thus, in the present case, if we suppose that the rainfall of the night of June 21 fell uniformly during the twelve hours from 6 p. m. to 6 a. m., we can readily compute that the observed increased amount of ground water was equivalent for each mile of valley along the river to a continuous flow of water amounting to 23.8 cubic feet per second. To put this in other words, we can say that if the sands of the valley had contributed to the river by seepage all of the water which the rain added to these same sands, the seepage would amount to a continuous

ow into each mile of the river of 23.8 cubic feet per second, maintained for twelve hours.

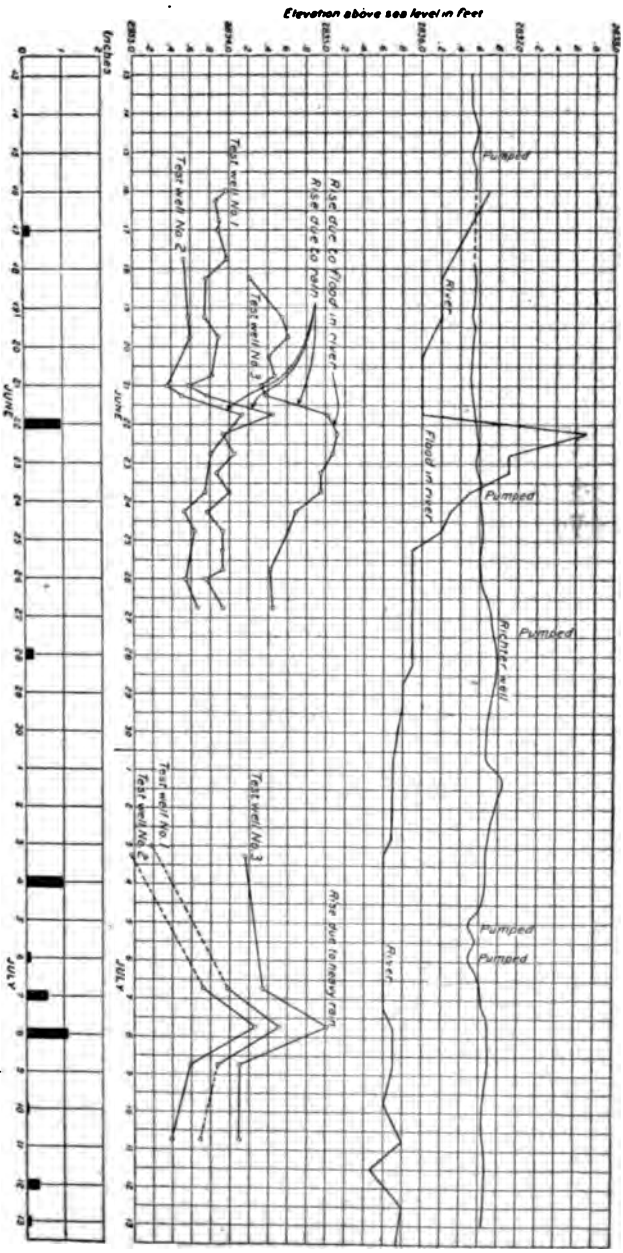


Fig. 10.—Elevation of water in Arkansas River and test wells, Garden, Kans., from June 16 to July 11, 1904. Test well No. 1 is 1,070 feet north of river; test well No. 2 is 190 feet east of test well No. 1; test well No. 3 is 980 feet north of river; Richter well is 2,600 feet north of river.

In a similar way, if the water contributed to the ground by the flood in the river from 3 p. m. to 6 p. m. of June 22 be considered as spread uniformly over twelve hours, it can readily be computed that the gain by the ground due to this cause represents a seepage loss for each mile

of the river of 6.4 cubic feet of water per second. It can readi seen, therefore, that the rainfall contributed a much greater volu water to the underflow than was contributed by the flood in the r

The average rise of the ground water during the night of Ju was such that it would require a rainfall, without run-off, of 2.2 i to fully account for it. The rainfall recorded at Garden for the of June 21 was 0.94 inch. The difference between the measured r the ground water and the rainfall is explained by the fact that the almost no run-off from the level lands of the river valley, so that n all of the drainage is underground by means of the deposits of s and gravels. The seepage of this drainage is in part toward the water plane along and near the river channel. At such a plac amount of rise in the ground water would naturally be higher could be accounted for by the localized rainfall.

After the high water of June 22 the river gradually fell unti the morning of June 27, it had reached an elevation of 2,835.9 which was 0.1 foot lower than its elevation on the morning of Jun The water in the test wells gradually fell during the same period, corresponding loss of ground water being given in Table 8 as a tinuous flow of water expressed in cubic feet per second for 1 mil river valley. By the morning of June 27 nearly all of the water tributed to the sands of the valley by the rain of June 21 and the f of June 22 had disappeared. The gain and loss can be expresse follows, in the form of a balance sheet:

TABLE 8.—*Loss and gain of ground water per mile of river valley, 1904.*

I.—FROM RIVER TO WELL NO. 1, 1,070 FEET NORTH OF RIVER, GARDEN, KANS.

Time.	Gain in ground water per mile of river valley.	Remarks.
	Sec. feet.	
June 18, 6 p. m., to June 21, 6 p. m.	− 0.93	No change in elevation of river w and only slight change in elev of water in well No. 1 until Ju
June 21, 6 p. m., to June 22, 6 a. m.	25.8	Due to rainfall of 0.94 inch.
June 22, 6 a. m., to June 22, 6 p. m.	7.3	Due to rise in river.
June 22, 6 p. m., to June 23, 6 a. m.	− 5.4	
June 23, 6 a. m., to June 24, 6 a. m.	− 3.1	
June 24, 6 a. m., to June 27, 6 a. m.	− 2.7	
July 3, 6 p. m., to July 7, 6 a. m.	2.3	Due to rain. No change in elev of river water.
July 7, 6 a. m., to July 8, 6 a. m.	22.4	Due to rain night of July 7. change in elevation of river w
July 8, 6 a. m., to July 9, 6 a. m.	−14.6	Rate of loss during 24 hours afte cipitation of 1.2 inches of nig July 7.
July 9, 6 a. m., to July 11, 6 a. m.	− 1.0	

TABLE 8.—*Loss and gain of ground water per mile of river valley, 1904*—Continued.

II.—FROM RIVER TO WELL NO. 2, 900 FEET NORTH OF RIVER, SHERLOCK, KANS.

Time.	Gain in ground water per mile of river valley.	Remarks.
	Sec. feet.	
July 15, 9 a. m., to July 20, 7.30 a. m	− 2.0	
July 20, 7.30 a. m., to July 25, 6 a. m	− 1.0	
July 27, 11 a. m., to July 27, 1 p. m	54.0	
July 27, 1 p. m., to July 27, 3 p. m	72.0	
July 27, 3 p. m., to July 27, 5 p. m	65.0	
July 27, 5 p. m., to July 27, 7 p. m	37.0	
July 27, 7 p. m., to July 28, 6 a. m	1.5	
July 28, 6 a. m., to August 1, 6 a. m	− 1.8	

III.—FROM RIVER TO WELL NO. 5, 550 FEET SOUTH OF RIVER, SHERLOCK, KANS.

July 18, 7 a. m., to July 20, 7 a. m	− 1.35	
July 20, 7 a. m., to July 25, 7 p. m	− .54	
July 25, 7 p. m., to July 27, 11 a. m	− .20	
July 27, 11 a. m., to July 27, 1 p. m	63.8	
July 27, 1 p. m., to July 27, 3 p. m	28.9	
July 27, 3 p. m., to July 27, 5 p. m	13.4	
July 27, 5 p. m., to July 27, 7 p. m	1.34	
July 27, 7 p. m., to July 29, 8 a. m	− .22	
July 29, 8 a. m., to August 1, 8 a. m	− .92	

V.—FROM WELL NO. 5 TO WELL NO. 6, 2,500 FEET SOUTH OF RIVER, SHERLOCK, KANS.

July 18, 7 a. m., to July 20, 12 m	− 2.6	
July 20, 12 m., to July 25, 8 a. m	− 1.5	
July 25, 8 a. m., to August 1, 8 a. m	− .5	

V.—FROM RIVER TO WELL NO. 2, 1,730 FEET SOUTH OF RIVER, DEERFIELD, KANS.

August 4, 9 a. m., to August 9, a. m	− 0.51	
August 6, 9 a. m., to August 8, 7.30 a. m	5.26	
August 8, 7.30 a. m., to August 9, 9 a. m	1.82	
August 9, 9 a. m., to August 10, 7.30 a. m	− .61	

Summary of loss and gain of ground water per mile of river valley.

	Cubic feet.	Acre-feet.
GAIN.		
Rain of night of June 21. From 6 p. m., June 21, to 6 a. m., June 22, 12 hours, at 23.8 cubic feet per second	1,030,000	23.6
Flood of afternoon of June 22. From 6 a. m., June 22, to 6 p. m., June 22, 12 hours, at 7.3 cubic feet per second	315,000	7.2
Total gain	1,345,000	30.8
LOSS.		
6 p. m., June 22, to 6 a. m., June 23, 12 hours, at 5.4 cubic feet per second	233,000	5.4
6 a. m., June 23, to 6 a. m., June 24, 24 hours, at 3.1 cubic feet per second	268,000	6.1
6 a. m., June 24, to 6 a. m., June 27, 72 hours, at 2.7 cubic feet per second	700,000	16.1
Total loss	1,201,000	27.6
Net gain	144,000	3.2

of the river of 6.4 cubic feet of water per second. It can readily b seen, therefore, that the rainfall contributed a much greater volume o water to the underflow than was contributed by the flood in the rive

The average rise of the ground water during the night of June 2 was such that it would require a rainfall, without run-off, of 2.2 inch to fully account for it. The rainfall recorded at Garden for the nigl of June 21 was 0.94 inch. The difference between the measured rise o the ground water and the rainfall is explained by the fact that there almost no run-off from the level lands of the river valley, so that nearl all of the drainage is underground by means of the deposits of sanc and gravels. The seepage of this drainage is in part toward the low water plane along and near the river channel. At such a place th amount of rise in the ground water would naturally be higher tha could be accounted for by the localized rainfall.

After the high water of June 22 the river gradually fell until, o the morning of June 27, it had reached an elevation of 2,835.9 fee which was 0.1 foot lower than its elevation on the morning of June 2 The water in the test wells gradually fell during the same period, th corresponding loss of ground water being given in Table 8 as a co tinuous flow of water expressed in cubic feet per second for 1 mile o river valley. By the morning of June 27 nearly all of the water co tributed to the sands of the valley by the rain of June 21 and the floc of June 22 had disappeared. The gain and loss can be expressed a follows, in the form of a balance sheet:

TABLE 8.—*Loss and gain of ground water per mile of river valley, 1904.*

I.—FROM RIVER TO WELL NO. 1, 1,070 FEET NORTH OF RIVER, GARDEN, KANS.

Time.	Gain in ground water per mile of river valley.	Remarks.
	Sec. feet.	
June 18, 6 p. m., to June 21, 6 p. m.	− 0.93	No change in elevation of river wate and only slight change in elevatic of water in well No. 1 until June 2
June 21, 6 p. m., to June 22, 6 a. m.	23.8	Due to rainfall of 0.94 inch.
June 22, 6 a. m., to June 22, 6 p. m.	7.3	Due to rise in river.
June 22, 6 p. m., to June 23, 6 a. m.	− 5.4	
June 23, 6 a. m., to June 24, 6 a. m.	− 3.1	
June 24, 6 a. m., to June 27, 6 a. m.	− 2.7	
July 3, 6 p. m., to July 7, 6 a. m.	2.3	Due to rain. No change in elevati of river water.
July 7, 6 a. m., to July 8, 6 a. m.	22.4	Due to rain night of July 7. change in elevation of river wat
July 8, 6 a. m., to July 9, 6 a. m.	−14.6	Rate of loss during 24 hours after p cipitation of 1.2 inches of night July 7.
July 9, 6 a. m., to July 11, 6 a. m.	− 1.0	

TABLE 8.—*Loss and gain of ground water per mile of river valley, 1904*—Continued.

II.—FROM RIVER TO WELL NO. 2, 900 FEET NORTH OF RIVER, SHERLOCK, KANS.

Time.	Gain in ground water per mile of river valley.	Remarks.
	Sec. feet.	
July 15, 9 a. m., to July 20, 7.30 a. m	− 2.0	
July 20, 7.30 a. m., to July 25, 6 a. m	− 1.0	
July 27, 11 a. m., to July 27, 1 p. m	54.0	
July 27, 1 p. m., to July 27, 3 p. m	72.0	
July 27, 3 p. m., to July 27, 5 p. m	65.0	
July 27, 5 p. m., to July 27, 7 p. m	37.0	
July 27, 7 p. m., to July 28, 6 a. m	1.5	
July 28, 6 a. m., to August 1, 6 a. m	− 1.8	

III.—FROM RIVER TO WELL NO. 5, 550 FEET SOUTH OF RIVER, SHERLOCK, KANS.

July 18, 7 a. m., to July 20, 7 a. m	− 1.35	
July 20, 7 a. m., to July 25, 7 p. m	− .54	
July 25, 7 p. m., to July 27, 11 a. m	− .20	
July 27, 11 a. m., to July 27, 1 p. m	63.8	
July 27, 1 p. m., to July 27, 3 p. m	28.9	
July 27, 3 p. m., to July 27, 5 p. m	13.4	
July 27, 5 p. m., to July 27, 7 p. m	1.34	
July 27, 7 p. m., to July 29, 8 a. m	− .22	
July 29, 8 a. m., to August 1, 8 a. m	− .92	

IV.—FROM WELL NO. 5 TO WELL NO. 6, 2,500 FEET SOUTH OF RIVER, SHERLOCK, KANS.

July 18, 7 a. m., to July 20, 12 m	− 2.6	
July 20, 12 m., to July 25, 8 a. m	− 1.5	
July 25, 8 a. m., to August 1, 8 a. m	− .5	

V.—FROM RIVER TO WELL NO. 2, 1,730 FEET SOUTH OF RIVER, DEERFIELD, KANS.

August 4, 9 a. m., to August 9, a. m	− 0.51	
August 6, 9 a. m., to August 8, 7.30 a. m	5.26	
August 8, 7.30 a. m., to August 9, 9 a. m	1.82	
August 9, 9 a. m., to August 10, 7.30 a. m	− .61	

Summary of loss and gain of ground water per mile of river valley.

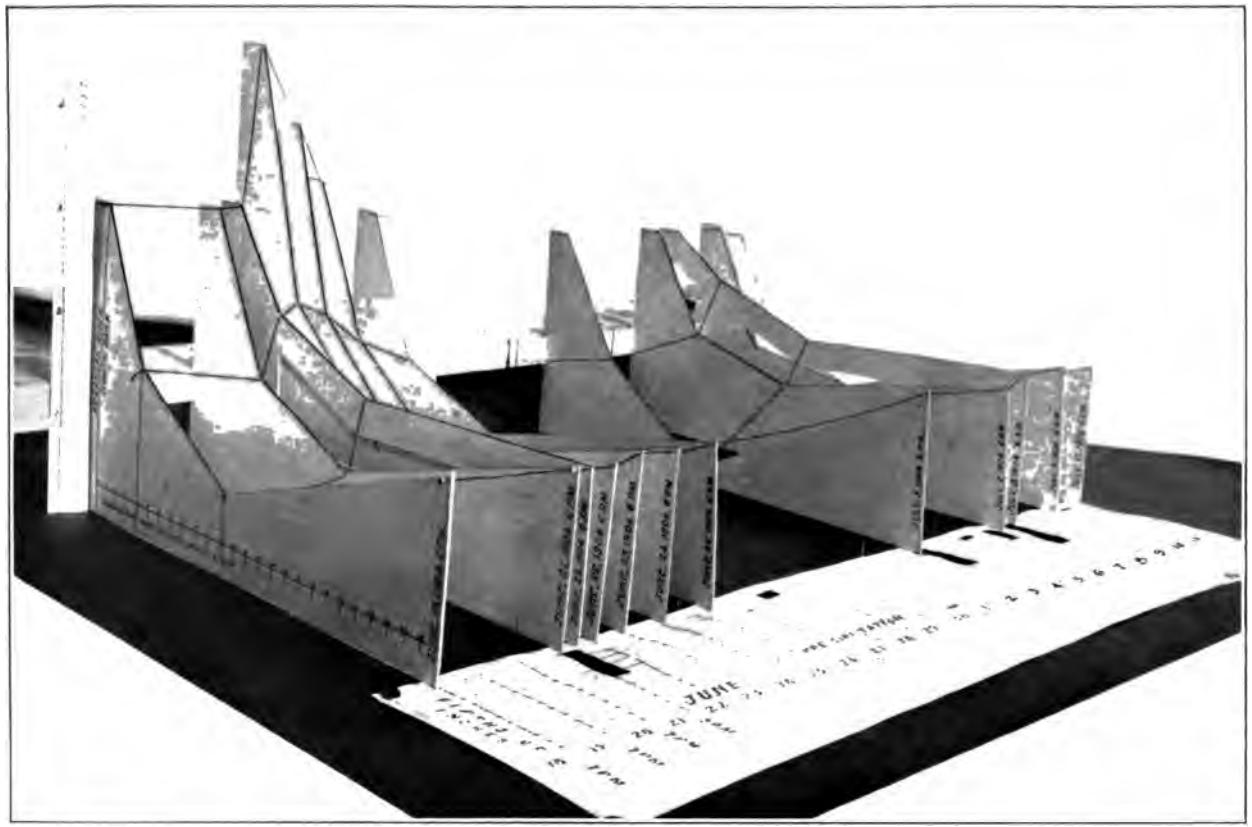
	Cubic feet.	Acre-feet.
GAIN.		
Rain of night of June 21. From 6 p. m., June 21, to 6 a. m., June 22, 12 hours, at 23.8 cubic feet per second	1,030,000	23.6
Flood of afternoon of June 22. From 6 a. m., June 22, to 6 p. m., June 22, 12 hours, at 7.3 cubic feet per second	315,000	7.2
Total gain	1,345,000	30.8
LOSS.		
6 p. m., June 22, to 6 a. m., June 23, 12 hours, at 5.4 cubic feet per second	233,000	5.4
6 a. m., June 23, to 6 a. m., June 24, 24 hours, at 3.1 cubic feet per second	268,000	6.1
6 a. m., June 24, to 6 a. m., June 27, 72 hours, at 2.7 cubic feet per second	700,000	16.1
Total loss	1,201,000	27.6
Net gain	144,000	3.2

In Pl. I there is shown a view of a model designed to illustra the changes in ground-water levels which have just been discusse This model shows, by cardboard cross sections, the level of the wate in Arkansas River and in three wells north of the river on variou dates in June and July, 1904. These are the same wells and the sam data given in Table 8 and represented graphically in fig. 10. Th height of the river is represented at the left end of each cardboar section and the position of the surface of the ground water in the thre wells appears at the appropriate distances to the right, the wells bein indicated by vertical lines and by the right end of the card. The wel represented by the right end of each cardboard section is located abou 2,500 feet north of the north bank of the river.

The surface of the ground water is represented in the model by th straight lines forming the top of each piece of cardboard. Of cours the actual surface did not consist of a broken line, as shown, but of curved line passing smoothly through the angles of the broken line The representation of the ground-water surface as straight line between the various wells introduces no substantial error in th results, and it illustrates the characteristic changes with greater fide ity than curved lines, whose forms, in any case, could be known on approximately.

It can readily be observed from this diagram that the river ar water plane remained substantially stationary from June 18 to June 2 The influence of the heavy rain of the night of June 21 is shown c the third cardboard section by the more elevated water plane of th next morning, the river remaining stationary during this interva The fourth cardboard cross section (6 p. m., June 22) shows the rive flood, which began at 3 p. m. June 22. This cross section shows that th water plane sank, notwithstanding this heavy flood, except at the we nearest the river. The river gradually fell, the water plane also fal ing at the same time. The model shows the water plane at its lowe observed position on July 3. The section shown in the model fo July 7 illustrates the influence of the rains falling from July 3 t July 7 in raising the water plane. The greatest rise in the water plan observed at any time is shown in the model by the third section fro the end, that corresponding to the morning of July 8. This rise wa due to a rain of more than 1 inch on the night before. As in the pr vious instances, the water plane rapidly fell away after the rise. I is important to bear in mind that the height of the river remaine almost constant from July 3 to 9.

These same changes are also shown in fig. 10, where a curve is give for the changing height of water in each well and the river. In usin this diagram or the table it is important to know that it is usuall necessary to compare evening observations with evening observation and not with morning observations. Owing to changes in temper



CARDBOARD MODEL OF CHANGES IN WATER PLANE NEAR CAMP 1.

ure and barometer there are diurnal periodic changes in the position of the water plane, and these fluctuations are such that it is always more satisfactory to compare observations taken at corresponding times of the day, unless the intermediate changes are very violent. The morning level of the ground water is normally higher than the

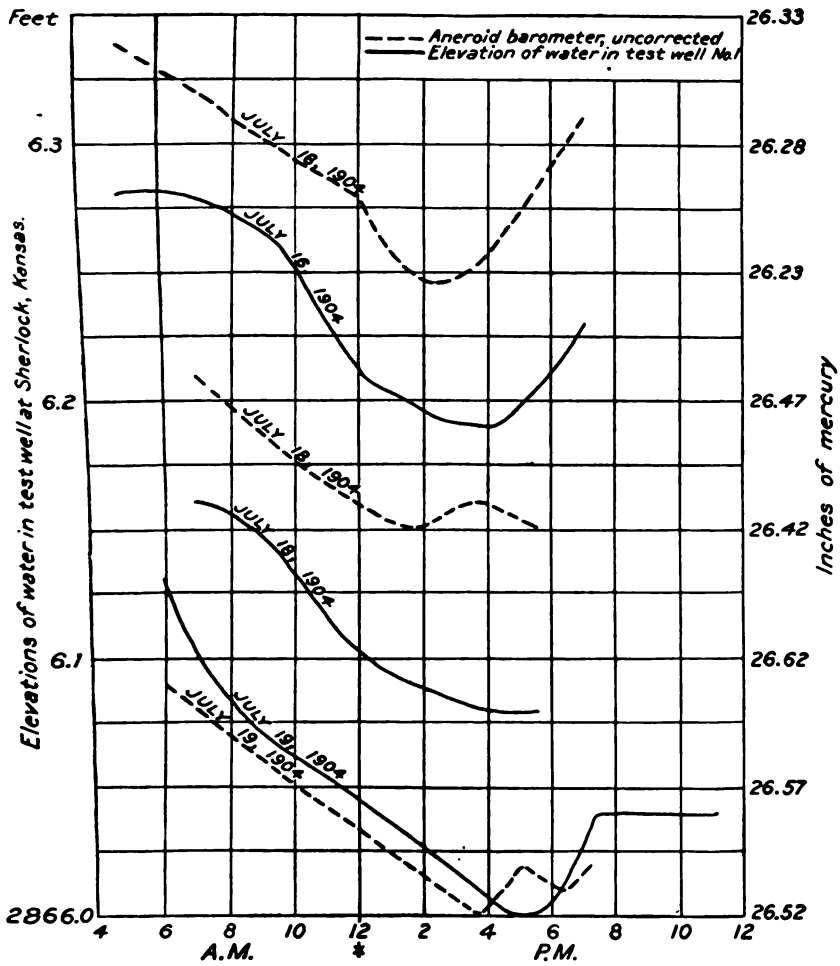


FIG. 11.—Curves of barometric pressure and height of water plane, showing correspondence between the fluctuations of the barometer and the water plane as observed on several dates at Sherlock, Kans. The dotted lines give the diurnal variations in the barometric pressure; the full lines show the elevations of the water in test well No. 1.

evening level, the fluctuations in the wells discussed above being indicated very clearly by some of the lines in fig. 10, especially those showing the June fluctuations in test wells Nos. 1, 2, and 3.

Some results showing the correspondence between the barometric pressure and the ground-water elevation were sought for at camp 1,

near Sherlock, Kans. The data obtained are depicted graphically in fig. 11. The results were not what were expected, as the influence of the barometric pressure should be to raise the ground water as the barometer falls.[a] This indicates that the low position of the ground water in the afternoon of each day is probably a temperature effect, due to the decrease in the capillarity of the water with the temperature. The ground water at test well No. 1, Sherlock, and in test wells Nos. 1, 2, and 3, Garden, was within 3 feet of the surface of the ground and the difference in temperature of day and night was very great.

In fig. 10 the level of water in the Richter well, 2,500 feet north of the river, is compared for a period of about thirty days with the elevation of the water in Arkansas River. The total variation of the water plane, as shown by the levels observed in the well twice daily during the thirty-day interval, did not exceed 2 inches. This shows that the influence of the river upon the ground water dies out to practically nothing in a distance of one-half mile. The influence of the rainfall upon the water in the well is traceable by a comparison of the rainfall record and the well curve, but it is uncertain whether any connection can be detected between the elevation of the river and the well curve. The influence of occasional pumping upon the ground-water level is quite pronounced.

The observations given above indicate the following conclusions:

1. The level of the ground water shows a marked tendency to remain at a level lower than the channel of the river at a point about one-fourth mile north of the river channel.

2. The elevation of the water plane is very sensitive to the amount of rainfall, the rise in the water plane (due to a rain) in the first bottoms being greater than can be accounted for by the localized precipitation.

3. High water in the river has much less effect upon the level of the ground water than the rainfall, its influence being confined to a distance of a few hundred feet from the river channel.

4. The water plane falls at a very rapid rate after its elevation has been increased by rainfall or by a flood in the river.

5. The fact that the water plane lies for a considerable distance at a level lower than the river channel, even when there is water in the river for an extended length of time, and the rapid way in which the ground water sinks after its rise due to heavy rain, establishes the fact that the underground drainage through the sands and gravels beneath the river valley is more than sufficient to carry off all of the rainfall without run-off into the river channel.

[a] Slichter, C. S., Motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 73.

FLUCTUATION OF GROUND-WATER LEVEL AT SHERLOCK, KANS.

Observations of changes of level of ground water near Sherlock, Kans., were made during the period extending from July 15 to August 3, 1904. For this purpose a number of test wells were driven, the location of which is shown in fig. 4. Of these test wells, No. 2 was 900 feet and No. 3 was 400 feet north of the river; No. 5 was 550 feet and No. 6 was 2,500 feet south of the river. The complete record of observations taken in the field is given in Table 9. The principal results presented by this table are shown graphically in fig. 12. As shown by this diagram, Arkansas River gradually fell from July 15 until July 27. At this time the water in the river had reached a very low stage, the flowing water occupying a width in the channel of about a rod and a depth of about 6 inches.

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TABLE 9.—*Elevation of water in river and in test wells, Sherlock, Kans.*

[Datum: 2,800 feet above mean sea level.]

Date.	Time.	Elevation of water in well No. 1.	Hydraulic gradient per mile from well No. 2 to well No. 1.	Elevation of water in well No. 2; 900 feet north of river.	Hydraulic gradient per mile from well No. 2 to well No. 3.	Elevation of water in well No. 3; 400 feet north of river.	Hydraulic gradient per mile from well No. 3 to river.	Elevation of water in river.	Hydraulic gradient per mile from well No. 5; 550 feet south of river.	Elevation of water in well No. 5; 550 feet south of river.	Elevation of water in well No. 6; 2,500 feet south of river.	Hydraulic gradient per mile from well No. 6 to well No. 5.	Elevation of water in well No. 4; 1,000 feet south of river.	Hydraulic gradient per mile from well No. 5 to well No. 4.	Barometer pressure of mercury, uncorrected.
1904.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Inches.*
July 15	9 a. m.	66.36	9.1	65.50	2.4	65.73	2.9	65.95							26.34
July 16	5 a. m.	66.28	8.8	65.45	4.5	65.68									26.32
Do	9.30 a. m.	66.26						65.85							
Do	10.30 a. m.	66.24													26.27
Do	12 m	66.21	9.8	65.28	3.1	65.57									26.26
Do	1.30 p. m.	66.20													26.23
Do	3.30 p. m.	66.19													26.23
Do	7 p. m	66.23													26.29
July 17	8 a. m.	66.23						65.75							26.45
Do	11.30 a. m.	66.21	9.5	65.31	2.2	65.52									26.35
July 18	7 a. m.	66.16	9.3	65.28	2.1	65.48	2.4	65.60	3.3	65.94	65.32	1.7	67.07	7.9	26.48
Do	10.45 a. m.	66.12	9.8	65.19	2.5	65.43				65.93	65.28	1.8	67.00	7.5	26.44
Do	12 m	66.10	9.7	65.18	2.6	65.43									26.43
Do	1.30 p. m.	66.09	9.8	65.16	2.7	65.42				65.90	65.26	1.7	66.97	7.4	26.42
Do	3.30 p. m.	66.08	9.9	65.14	2.8	65.41				65.89	65.25	1.7	66.95	7.4	26.44
Do	5.30 p. m.	66.08	9.6	65.16	2.6	65.41	3.2	65.65	2.2	65.88	65.24	1.7	66.95	7.4	26.42
July 19	6 a. m	66.13						65.55							26.61
Do	8 a. m	66.08													26.59
Do	10 a. m	66.06													26.57
Do	3.40 p. m.	66.01													26.52
Do	5 p. m	66.00	9.9	65.06	2.1	65.26					65.17				26.54
Do	6.15 p. m.	66.01													26.53
Do	7.15 p. m.	66.04						65.45							26.54
Do	9.15 p. m.	66.04													
Do	11.15 p. m.	66.04													

July 20	7.30 a. m	65.99	9.5	65.09	.9	65.18	.9	65.25	5.4	65.81			66.96	8.1	26.02
Do	12 m	65.93								65.79	65.17	1.7			26.54
July 21	4 p. m	65.86	10.0	64.91	.6	64.97	.4	65.10		65.70	65.12	1.6	66.82		26.46
Do	7 p. m	65.87						65.00							26.50
July 22	2 p. m									65.76	65.19	1.5	66.97		
Do	5 p. m							65.15			65.16				
July 23	3 p. m							65.05	5.9	65.66	65.11	1.5	66.81	8.1	
July 24	6 p. m	65.79	9.9	64.85	.3	64.88	1.6	65.00							
July 25	7 a. m	65.82	9.4	64.93	.2	64.95	.7	65.10							
Do	10 a. m			64.83	.5	64.88									
Do	6 p. m	65.74	10.0	64.79	.5	64.84	2.1	65.00	5.1	65.53	65.03	1.4	66.67	7.9	
July 26	9.30 a. m							65.05		65.52	65.02	1.4	66.69	8.1	
Do	5 p. m							65.00		65.49	64.99	1.4	66.64	8.0	
July 27	11 a. m	65.70	10.0	64.75	.8	64.83	1.7	65.00		65.46	64.97	1.3	66.62	8.1	26.51
Do	1 p. m			64.73	1.7	64.89	14.6	66.00	4.0	65.42					
Do	3 p. m	65.80	9.8	64.87	4.4	65.29	14.6	66.40	9.2	65.44	64.95	1.3	66.57	7.9	
Do	5 p. m	65.91	8.9	65.07	6.4	65.68	12.3	66.60	11.2	65.44					
Do	7 p. m	66.04	8.5	65.24	6.8	65.88	10.8	66.60	10.9	65.46					
July 28	6 a. m	66.21	8.0	65.45	5.3	65.95	5.3	66.35							
July 29	8 a. m	66.25	9.0	65.40	5.1	65.88	5.5	66.30	5.8	65.70	64.89	2.2	66.78	7.5	
July 30	8 a. m	66.12	9.0	65.27	3.1	65.56	4.5	65.90							
July 31	8 a. m									65.71					
August 1	8 a. m	66.10	9.2	65.23	2.9	65.50	2.6	65.70	.2	65.72	64.79	2.5	66.79	7.5	
August 2	6 p. m							65.45							
August 3	7 a. m							67.10							

During this same period of fall in the river there was no rai except on July 22 and a very light rain on July 25. The rain of

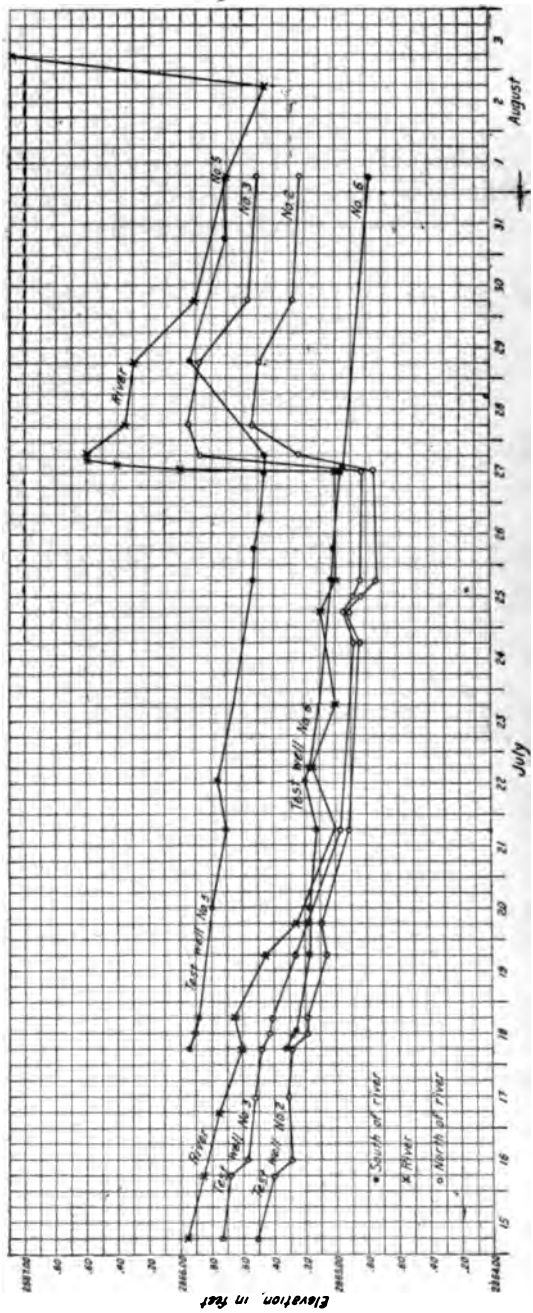
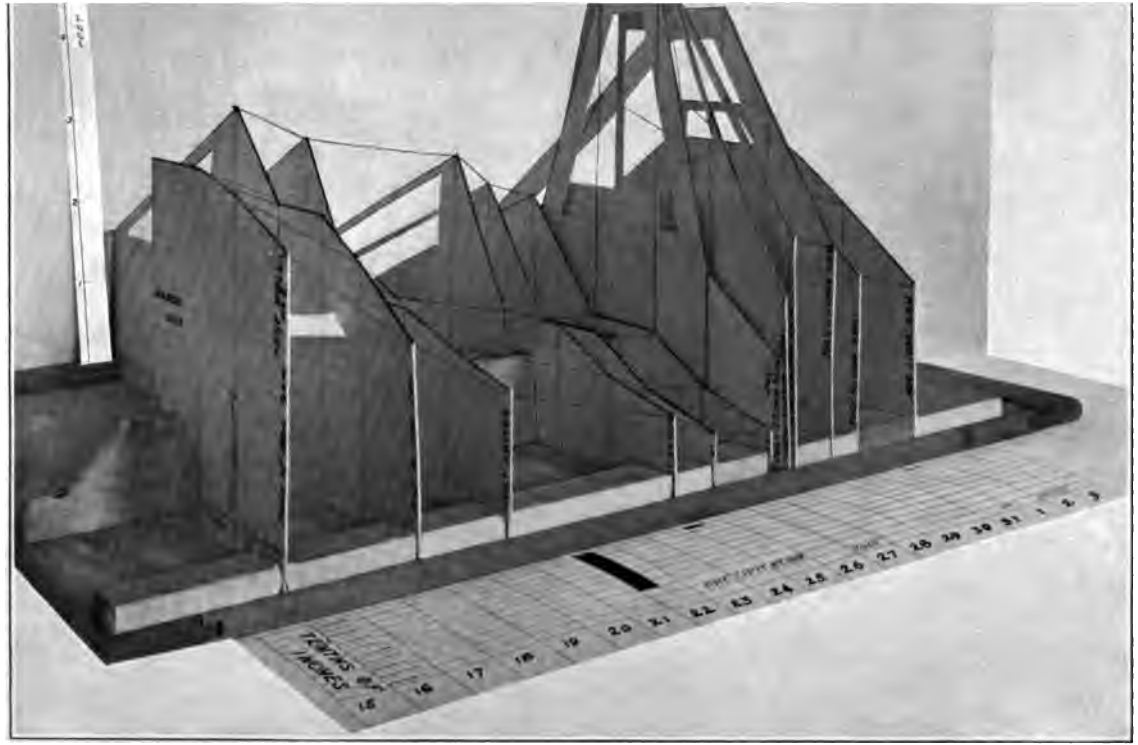


FIG. 12.—Elevation of water in test wells and in Arkansas River for the various dates from July 15 to August 3, 1904, at Sheirock. Preceding the entries in this diagram considerable rain had fallen. There were several heavy rains between July 3 and 13. These rains undoubtedly account for the high position of the water plane in all of the wells at the beginning of the period for which the diagram is constructed. Test well No. 2 is 900 feet north of river; test well No. 3 is 400 feet north of river; test well No. 5 is 550 feet south of river; test well No. 6 is 2,500 feet south of river.

22 was measured at Garden by the volunteer observer of the Un States Weather Bureau as 1.42 inches, but the rainfall at Sherl was very much less. During this period of fall of level of the wa



CARDBOARD MODEL OF CHANGES IN WATER PLANE NEAR SHERLOCK, KANS.

the river the test wells north of the river fell at corresponding
:es. The total fall in the river amounted to 0.95 of a foot; the fall
test well No. 3, 400 feet north of the river, during the same period
s 0.9 of a foot; in test well No. 2, 900 feet north of the river, 0.77
a foot; in test well No. 5, 550 feet south of the river, 0.5 of a foot;
d in test well No. 6, 2,500 feet south of the river, 0.3 of a foot.
ı July 27, between 11 a. m. and 5 p. m., the river rose 1.6 of a foot,
storing the level of water in the river to the height of July 15 plus
3 of a foot. This sudden rise in the river was not accompanied by
infall in the neighborhood of Sherlock. Its influence upon the
rious test wells is shown by fig. 12. The immediate effect upon test
ells Nos. 2 and 3, north of the river, was very apparent. Between 11
m. and 7 p. m. test well No. 3, 400 feet north of the river, rose 1.05
et, and test well No. 2, 900 feet north of the river, rose 0.49 of a
ot. By the next morning at 6 a. m. the river had fallen 0.25 of a
ot; test well No. 3, 400 feet north of the river, had risen about 0.1
a foot, and test well No. 2, 900 feet north of the river, had risen
23 of a foot. The river continued to fall very slowly, on the morn-
g of July 29 having fallen only about one-half of 0.1 of a foot from
elevation on July 28; the water in test wells Nos. 2 and 3 had
opped about the same amount, and on August 1, at 8 a. m., when
e river had fallen 0.6 of a foot below its elevation of July 29, test
ells Nos. 3 and 2 had dropped 3.6 and 1.8 feet, respectively. During
is same period of time the water plane south of the river acted very
fferently from that observed on the north side of the river. The water
ı test well No. 6, 2,500 feet south of the river, fell continuously from
uly 18 to August 1, notwithstanding the flood of July 27; and that
n test well No. 5, 550 feet south of the river, fell from July 18 until
July 27, the total fall amounting to 0.47 of a foot. No observation
was made at this test well on July 28, but by the morning of July 29
he water had risen 0.45 of a foot. On August 1 it had fallen 0.2 of a
foot below its level on the morning of July 29, in sympathy with the
general fall of the water in the river. It can be seen from this that
the elevation of the water in the various test wells showed all varieties
of change during the flood in the river. The wells within 900 feet of
the river fluctuated quite accurately with the changing level in the
river itself, while the water in the test well one-half mile from the
river seemed to show no effect of the flood in the river during the
period of observation.

In explanation of the gradual fall in the test wells from July 18 to
July 27, it must be remembered that the position of the water, as
found on July 18, was high on account of the heavy rains which fell
during the first twelve days of July. From July 4 to July 13, inclu-
sive, 3.27 inches of rain were caught at the rain gage at Garden, Kans.;
the rainfall at Sherlock, Kans., was probably as great, so it is very
likely that the level of the water found in the test wells on July 1[illegible]

and 18 was high owing to the previous rains. In fig. 13 the resu of the flood of July 27 are shown in greater detail than in the previ diagram.

A photograph of a cardboard model showing the changing positi of the water plane at Sherlock is reproduced in Pls. II and III. ' top of each cardboard corresponds to a cross section of the water pl taken across the valley on a certain date, the right side of each c corresponding with the north side of the valley, the left side co

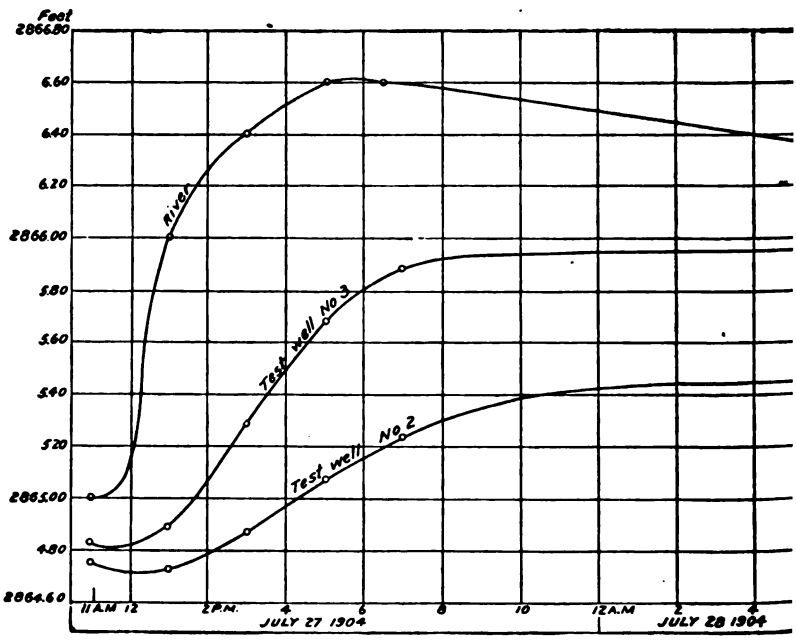
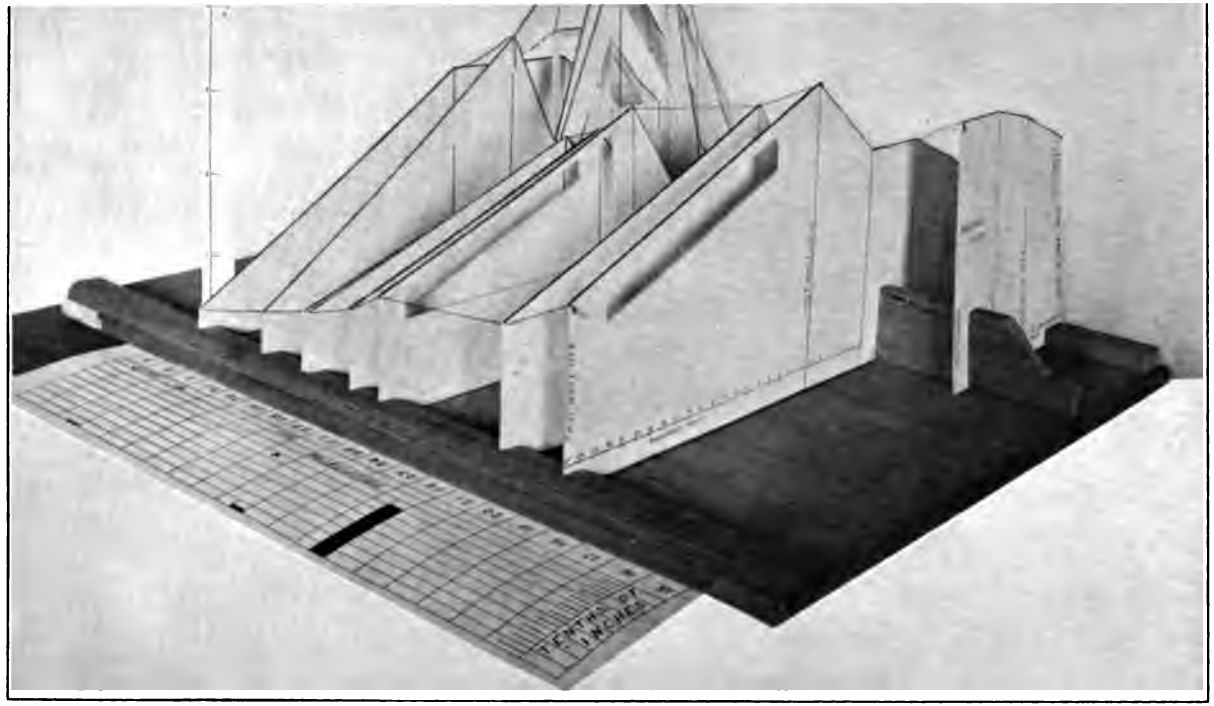


FIG. 13.—Elevation of water in Arkansas River and in two test wells near Sherlock, Kans., for v hours during the flood of July 27, 1904. The vanishing influence of the flood with incre distance from the river is clearly brought out by the diagram. Test well No. 2 is 900 feet of north bank of river; test well No. 3 is 400 feet north of north bank of river.

sponding with the south side of the valley. The location of each well is shown by a vertical line, and the position of the channel of Arkansas is indicated by the level segment of each card near the dle of each section. The model shows to the eye the way in w the river and the water in all of the test wells gradually fell from 13 to July 27, and it also illustrates the influence of the flood of 27 upon the wells near the river. It also shows that the level of w in well No. 6, one-half mile south of the river, was not influence the flood in the river, but continued to fall during the entire pe The decreasing influence of the river on the water plane with the tance from the river is brought out clearly by the diagram (fig. 1

It is apparent from this model, as well as from the one shown camp 1, that there is a marked tendency for the ground water the river, especially on the north side, to remain at a lower level



CARDBOARD MODEL OF CHANGES IN WATER PLANE NEAR SHERLOCK, KANS.

ie water in the river itself. At the time the data presented by the odel were obtained, there had been water in the river for six or seven eeks and the amount of rainfall had been above the average. These cts indicate that the underground drainage through the sands and ravels is more than sufficient to drain off the precipitation, without turn seepage into surface streams and without run-off from the surice of the ground.

The various amounts of ground water gained or lost by each mile f the valley along the river at Sherlock from July 15 to August 1, 904, is expressed in Sections II, III, and IV of Table 8 (p. 31). For the urpose of making the results as definite as possible the gain or loss or each mile of valley is given as a continuous flow of water expressed n cubic feet per second. Thus, according to the table, the strip of ground between the river bank and test well No. 2, 900 feet north of the river, extending along the stream for a distance of a mile, lost water from July 15 to to July 20 at a rate equivalent to a steady flow of water equal to 2 cubic feet per second. During the flood on July 27 this same strip of country absorbed water from the river during the first two hours of flood at the rate of 54 cubic feet per second. The rate of gain during the three following periods of two hours each was 72, 65, and 32.4 second-feet, respectively. During the eleven hours from 7 p. m., July 27, to 6 a. m., July 28, the rate of gain fell to 1.5 second-feet, after which the ground lost water. These results, and similar results for the south side of the river, are given in the able. Putting all of these results together we can compute the mount of water furnished to the sands by the flood in the river as ollows, the computation applying to 1 mile of the river valley only:

Water furnished to sands near Sherlock, Kans., by flood of Arkansas River.

	Cubic feet.
North of river:	
July 27, 11 a. m. to 1 p. m., 2 hours, at 54 cubic feet per second	389,000
July 27, 1 p. m. to 3 p. m., 2 hours, at 72 cubic feet per second	525,000
July 27, 3 p. m. to 5 p. m., 2 hours, at 65 cubic feet per second	467,000
July 27, 5 p. m. to 7 p. m., 2 hours, at 32.4 cubic feet per second	234,000
July 27, 7 p. m. to 6 a. m. July 28, 11 hours, at 1.5 cubic feet per second	59,500
Total gain	[a] 1,674,500
South of river:	
July 27, 11 a. m. to 1 p. m., 2 hours, at 63.8 cubic feet per second	459,000
July 27, 1 p. m. to 3 p. m., 2 hours, at 28.9 cubic feet per second	208,000
July 27, 3 p. m. to 5 p. m., 2 hours, at 13.4 cubic feet per second	96,500
July 27, 5 p. m. to 7 p. m., 2 hours, at 1.34 cubic feet per second	9,650
Total gain	773,150
July 27, 7 p. m. to 8 a. m. July 28, loss at 0.22 cubic foot per second	10,296
Net gain	[b] 762,854
Total gain both sides of river	[c] 2,437,354

[a] Equals 38.4 acre-feet. [b] Equals 17.6 acre-feet. [c] Equals 56 acre-feet.

The gain of 56 acre-feet took place on land having an area of 175 acres.

The above results show the gain between test well No. 2, 900 feet north of the river, and test well No. 5, 550 feet south of the river. There was some gain in ground water in the lands north and south of these boundaries, but the data are not at hand for the computation. The susceptibility of the adjoining lands in receiving seepage water from the river was greater on the north side than on the south side of the river.

FLUCTUATION OF GROUND-WATER LEVEL AT DEERFIELD, KANS.

Observation of the ground-water level was made at camp 3, near Deerfield, in three test wells. The location of these test wells appears on the map, fig. 6. The water in the river occupied but a small part of the river channel during most of the time during which these observations were made, and therefore the distances of the test wells from the edge of the flowing water are given in fig. 19, in preference to the distances from the river bank. Test well No. 1 was 1,100 feet, and well No. 2, 1,730 feet south of water in the river. Test well No. 3 was 1,100 feet south of the river, but 1,000 feet upstream from test well No. 2.

TABLE 10.—*Elevation of water in river and test wells at Deerfield, Kans.*

Date.	Time.	Elevation of water in well No. 1, 1,100 feet from river.	Hydraulic gradient, per mile, from well No. 1 to well No. 2.	Elevation of water in well No. 2, 1,730 feet from river.	Hydraulic gradient, per mile, from well No. 2 to well No. 3.	Elevation of water in well No. 3, 1,100 feet from river.	Hydraulic gradient, per mile, from river to well No. 3.	Elevation of water in river.
1904.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
August 4	9 a. m	2,923.02	0.25	2,922.99	8.7	2,924.57	−1.10	2,924.80
August 5	do	2,923.14	.17	2,923.12	9.0	2,924.75	1.44	2,924.45
August 6	do	2,923.21	.50	2,923.27	8.8	2,924.87	2.98	2,924.25
August 8	7.30 a. m	2,923.23	.50	2,923.29	8.4	2,924.82	−1.58	2,925.10
Do	10 a. m	2,923.23	.34	2,923.27	8.5	2,924.83	.....	.....
Do	12 m	2,923.23	.42	2,923.28	8.5	2,924.83	.....	.....
Do	4.30 p. m	2,923.23	.25	2,923.26	8.7	2,924.84	.....	.....
August 9	9 a. m	2,923.27	.17	2,923.29	8.8	2,924.89	−1.49	2,925.20
Do	2.30 p. m	2,923.29	.08	2,923.28	.....	.....	.....	.....
August 10	7.30 a. m	2,923.32	.00	2,923.32	8.7	2,924.91	1.73	2,924.55

The chart given in fig. 14 shows that a flood on August 7 in the river had no influence upon the water level in any of the wells although frequent observations were made to detect such influence. The diagram likewise shows the effect of the rain in raising the ground water as shown by all of the wells from August 4 to August 7. Dur-

ing this same interval the river was falling, while the ground water was rising. The rainfall was measured at camp by catching rain in a tin bucket and correcting for difference in area between top and bottom of bucket. The observed rainfall on August 4 and August 5 amounted to about 1.75 inches. The water in the various test wells rose by the following amounts between August 4 and August 6: Test well No. 1, 0.17 foot, or 2.02 inches; test well No. 2, 0.29 foot, or 3.48 inches; and test well No. 3, 0.30 foot, or 3.60 inches. If we assume that the soil had a porosity of 33⅓ per cent, these observed changes in the level of the water plane are equivalent to actual increments of 0.7, 1.16, and 1.2 inches, respectively. These amounts will average

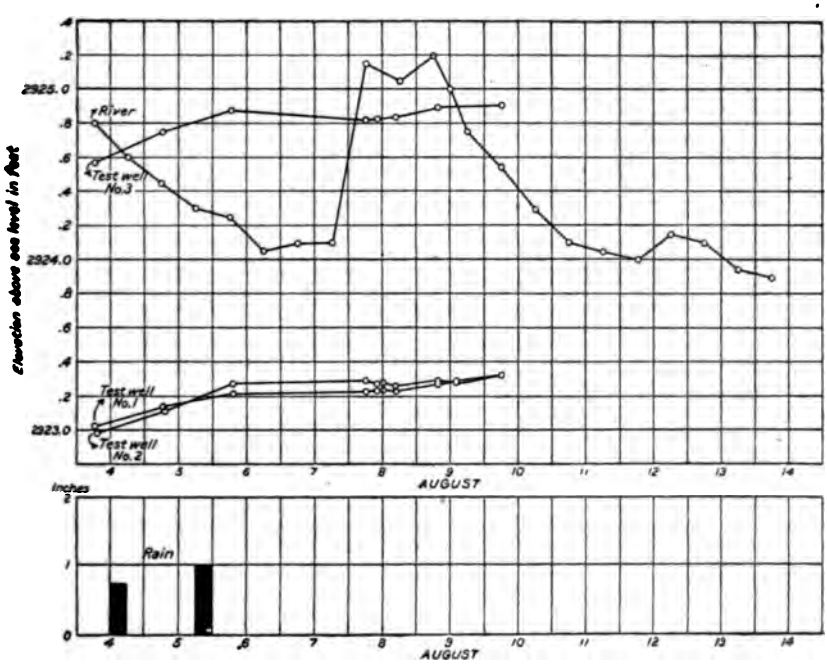


FIG. 14.—Elevation of water in Arkansas River and test wells at Deerfield, Kans., August 4 to 14, 1904. Test well No. 1 is 1,100 feet south of stream. Test well No. 2 is 1,730 feet south of stream. Test well No. 3 is 1,100 feet from stream and 1,000 feet from test well No. 2.

almost exactly 60 per cent of the rainfall for the two days, August 4 and August 5, 1904. This result gives very direct proof of the excellent quality of the catchment area furnished by the sandy bottom lands on the south side of the river at Deerfield.

EVAPORATION EXPERIMENTS NEAR DEERFIELD.

The table of meteorological data below has value in showing that a considerable amount of stored ground water is lost in the first bottoms of Arkansas River by evaporation. Although these measurements extend over only a very brief period, they are sufficient to establish

the fact that the loss of ground water by evaporation is about ten times as great where the water is within 1 foot of the surface of the ground as it is where the water lies at a depth of 3 feet. The pumping plants that materially lower the ground water in the bottom lands will thus save a considerable amount of water that now goes to waste in evaporation and in supplying the rank growth of wild grasses that flourish in the first bottom lands. It is safe to say that this savable loss amounts on the average to a foot of water for each acre of first bottoms for the months of July and August alone.

The following is a record of observations of evaporation from three tanks filled with natural soil in which the water plane was kept at a constant depth, compared with the evaporation from a tank of open water. The tanks were located in the bottom lands of Arkansas Valley, near the head gates of the Farmers' ditch. The soil is a sandy loam changing to coarse sand at a depth of about 3 feet.

Meteorological records at Deerfield, Kans., from July 3 to September 8, 1905.

Week of—	Rainfall in inches.	Vapor pressure.	Per cent of relative humidity.	Velocity of wind in miles.	Evaporation in inches.				
					Open water.	1 foot to water, soil cultivated.	1 foot to water; soil uncultivated.	2 feet to water.	3 feet to water.
July 3-9 [a]	0.11	.....	.....	16.50	.....	.....	.....	.....	0.13
July 9-16	0.0	.440	47.3	15.89	.....	.....	.....	.....	0.13
July 16-23	0.08	.482	50.2	16.13	2.53	.....	.....	.....	0.23
July 23-30	1.24	.560	61.2	19.78	2.39	.....	.....	.....	1.40
July 30-Aug. 6	1.50	.568	63.9	12.05	1.80	.....	.....	.....	0.05
Aug. 6-13	0.38	.478	54.8	13.62	2.45	1.48	1.73	0.65	0.43
Aug. 13-20	0.05	.530	57.3	13.26	2.22	1.34	1.21	0.60	0.17
Aug. 20-27	0.0	.520	49.3	19.58	3.04	1.14	1.38	0.49	0.08
Aug. 27-Sept. 3	0.03	.395	41.4	17.19	3.19	0.92	1.51	0.49	0.12
Sept. 3-8 [a]	0.71	.489	60.4	14.54	1.21	0.70	0.87	0.60	0.04

[a] Week incomplete.

CHAPTER III.

CHEMICAL COMPOSITION OF THE WATERS OF THE UNDERFLOW.

Chemical tests of the ground waters were made wherever possible during the process of the work. Portable field apparatus was at hand which could be used in making a few simple tests. The determinations made included titrations for chlorine, alkalinity, and hardness. Total solids were determined by means of the Whitney electrolytic bridge. The curve of total solids used in this case was obtained by evaporating a sample of water containing 95.9 parts per 100,000 total solids. The results of the test are brought together in Table 11, and the curve used for the determination of the total solids is printed as fig. 15 (p. 47).

TABLE 11.—*Analyses of ground water in the Arkansas Valley, western Kansas.*

WEST OF GARDEN, KANS.

Date.	Chlorine (parts per 100,000).	Alkalinity as $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.	Depth of well.	Location.
1904.					°*F.*	*Feet.*	
June 16	4.61	14.0	21.35	.....	.....	.....	River water.
June 20	.....	.....	.....	.....	71.0	.....	Do.
June 28	5.31	31.0	30.9	93	67.0	.....	Do.
July 11	5.85	13.75	49.1	105	88.0	.....	Do.
July 6	21.79	22.9	25.3	49	55.0	10	Windmill south of river.
July 5	8.10	16.5	.....	33	58.0	9	Station 12.
June 28	8.51	19.0	34.7	119	48.0	28	Station 8.
Do	11.00	22.0	37.6	127	51.0	17	Station 10.
June 21	8.51	17.0	33.9	113	58.5	17	Station 4.
June 20	.....	24.5	38.65	.....	.....	15	Station 2.
Do	6.72	15.0	43.20	.....	52.0	15	Station 1.
June 18	4.96	20.0	40.51	.....	.....	32	Station 3.
July 8	6.00	16.1	39.5	121	52.0	32	Station 6, well A.
Do	3.05	11.4	13.9	37	52.0	58	Do.
July 9	2.70	12.9	21.6	32	55.0	48	Station 6, well B.
Do	1.67	11.9	14.6	36	53.0	56	Do.
July 6	4.59	14.7	33.5	105	55.0	30	Station 11.
Do	5.42	20.4	38.8	114	52.0	16	Mrs. Richter's well at camp.
June 15	13.50	23.0	53.5	.....	.....	5	Do.
June 16	12.80	19.5	47.9	.....	.....	5	Do.
Do	9.60	22.0	48.0	.....	.....	3–4	Test well No. 1.
June 20	21.30	20.5	48.0	.....	59.0	3–4	Do.
Do	6.72	17.5	36.0	.....	62.5	3–4	Test well No. 3.
June 23	13.12	24.0	39.1	121	60.0	3–4	Do.
June 28	11.00	20.0	39.5	126	52.0	12	New well (camp).

TABLE 11.—*Analyses of ground water in the Arkansas Valley, western Kansas*—Co

WEST OF GARDEN, KANS.—Continued.

Date.	Chlorine (parts per 100,000).	Alkalinity as $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.	Depth of well.	Location.
1904.					°F.	Feet.	
June 16	8.88	19.5	39.9	.....	.....	12	New well (camp)
Do	10.62	22.5	43.7	.....	.....	14	Station 1.
July 7	.78	13.1	10.7	6	65.0	.....	Sand hills, sec. 36 S., R. 34 W.
Do	.67	13.6	11.2	6	57.0	.....	Do.
September 22	2.06	19.9	25.6	35	.....	16	Sec. 2, T. 23 S., R.
1905.							
January 24	4.2	19.2	53.3	86	.....	25	Poor farm.
Do	2.1	11.4	31.1	57	.....	20	Shultz.
Do	5.1	18.0	82.0	119	.....	40	L. C. Working.
Do	4.1	20.5	31.2	102	.....	36	A. Robinson.
Do	3.4	18.1	27.9	68	.....	a 13	Foreman.
Do	11.4	19.2	39.3	76	.....	115	Faye.
Do	17.6	22.7	45.9	150	.....	35	M. McClurken.
Do	1.2	18.5	21.3	26	.....	a 30	Frank Kolbus.

GARDEN, KANS.

1904.							
September 22	0.92	14.1	25.6	16	.....	130	Atchison, Topek Santa Fe R. R.
Do	.85	15.9	30.0	16	.....	110	Carter's well.
Do	3.96	20.3	69.2	80	.....	16+40	City waterworks
1905.							
January 24	1.6	18.8	29.5	42	.....	78	S. L. Leonard.

SHERLOCK, KANS.

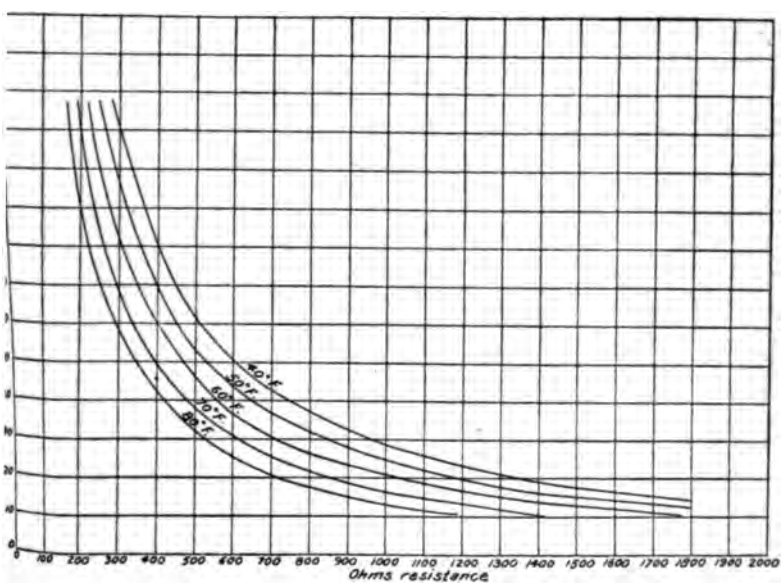
1904.							
July 16	4.04	13.20	27.70	73.0	71.0	.....	River water.
July 22	3.85	13.90	37.90	74.0	73.0	.....	Do.
July 16	.89	21.20	13.09	27.0	63.0	8	Test well No. 6.
July 19	.50	17.50	4.64	30.0	58.5	18	Station 16.
July 16	.58	21.50	2.38	56.0	60.0	8	Test well No. 4.
July 26	1.10	17.85	26.20	42.0	56.0	26	Station 20.
July 18	3.62	16.75	27.30	35.0	57.0	22	Station 15.
July 21	2.46	21.30	28.10	55.0	56.2	36	Station 17.
July 30	4.61	19.45	44.70	83.0	65.0	10	Near station 17.
July 22	4.58	15.90	40.60	80.0	56.0	22	Station 18.
Do	4.05	15.90	42.90	78.0	57.0	14	Do.
July 23	5.20	17.45	46.30	104.0	53.0	20	Station 19.
July 16	3.47	14.65	30.00	93.0	57.7	18	Station 14.
Do	5.10	15.75	31.10	97.0	55.0	22	Do.
July 15	5.18	15.50	.....	107.0	54.0	18	Station 13.
July 27	4.97	15.25	48.5	96.0	55.5	28	Station 21.
Do	4.90	16.25	50.6	97.0	57.5	28	Station 22.
July 19	.96	16.85	20.0	21.0	.....	.....	Sec. 30, T. 24 S., R.
Do	.17	19.00	25.9	37.0	.....	.....	Sec. 20, T. 24 S., R.
September 22	2.24	21.30	29.9	44.0	.....	40	Sec. 30, T. 22 S., R.

a To water.

11.—*Analyses of ground water in the Arkansas Valley, western Kansas*—Cont'd.

DEERFIELD, KANS.

ıte.	Chlorine (parts per 100,000).	Alkalinity as $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.	Depth of well.	Location.
104.					°F.	Feet.	
ıber 22..	1.49	15.1	31.2	22.0	66.0	10	NE. quarter sec. 26, T. 24 S., R. 35 W.
6.....	2.60	14.7	28.9	49.0	.....	24	SW. quarter sec. 24, T. 24 S., R. 35 W.
10.....	2.45	17.7	32.7	74.0	60.0	12	Near station 28.
9.....	5.00	15.7	51.2	95.0	56.0	24	Station 27.
4.....	7.60	16.2	55.2	117.0	59.5	12	Well at camp.
.....	6.64	15.3	57.0	114.0	58.0	25	Station 23.
8.....	5.11	16.0	48.4	90.0	57.0	37	Station 26.
4.....	8.61	17.7	65.9	117.0	59.5	6	Test well No. 1.
5.....	5,32	15.5	44.4	108.0	59.0	21	Station 24.
6.....	5.39	16.7	48.3	106.0	57.0	16	Station 16.



15.—Curve for Whitney electrolytic bridge used in converting resistance in ohms into total solids for ground waters of Arkansas Valley.

A comparison of the results of the tests at various stations shows a ırked decrease in the quantity of dissolved solids in the water with e depth at which the sample was taken. In forcing down test wells almost any point in the bottom lands of Arkansas River the increas f softness of the water can be noted almost from foot to foot. At a nsiderable depth, say from 60 to 100 feet or more, there are found ters which are popularly called in this region "second" or "third" ters, which are very much softer than the water obtained from

shallow wells. At points located in the sand hills south of the rive there are places where shallow wells furnish water much softer tha the so-called second or third waters found in the vicinity of Garden

The total solids in the ground water determined at wells in the firs camp, 2 miles west of Garden, varied from 121 parts per 100,000 fo water taken 4 feet below the water plane to 103 parts per 100,000 fo water taken at 6 feet, and 80 parts per 100,000 for water taken at 1 feet. Water taken from the railroad well, 130 feet deep, at Garden showed total solids of 16 parts per 100,000. Water in the sand hill south of the river at a depth of 9 feet showed 33 parts per 100,00 total solids, and another well, deeper, but of unknown depth, showe 6 parts per 100,000 total solids. The tendency of the ground wate near the surface in the bottom lands of the river to run high in solid seems to indicate that this increased hardness is due to the loss of th ground water by evaporation. The water plane in these bottom land lies close to the surface of the ground and is subject to frequent flu tuations due to rain and changes of conditions in the river itsel These changes are sufficient to account for a large excess of dissolve solids in the surface waters, and it is believed that no other explan tion is necessary. As the ground water moves downstream, the va ous filaments of moving water must thread themselves around t grains of sand and gravel, continually dividing and subdividing t water as it moves through the capillary pores. The effect of this actic is to slowly work the concentrated water near the surface down t greater depths, forming a ground water of graduated strengt Every layer of silt, clay, or other impervious material which possess a considerable area acts as a partition, separating the moving groun water into layers which do not mix, except where the impervio strata give out. This results in layers of water of distinct differenc in total solids, which are locally known as "first," "second," an "third" water, etc.

In the following table (Table 12) the various samples of grou water are classified by depth of the wells, and the averages of the di ferent determinations are tabulated. From this arrangement a co parison is possible between the waters of different depths, in whi the errors due to special peculiarities of particular wells are part eliminated. Some of the well water taken from stock or domes wells showed marked pollution, but all such samples have be included in the table.

TABLE 12.—*Quality of ground water in Arkansas River Valley, as determined from the averages of classified samples.*

Classification.	Chlorine (parts per 100,000).	Alkalinity $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.
Wells under 10 feet deep:					° F.
Average of 11 samples	10.32	20.84	38.53	75.80	60.50
Probable error	1.45	.434	3.76	10.47	.735
Error ... per cent	14.05	2.08	9.77	13.83	1.21
Wells 10 to 20 feet deep:					
Average of 18 samples	7.77	18.55	40.13	96.73	56.15
Probable error	.829	.520	1.321	4.87	.795
Error ... per cent	10.66	2.80	3.30	5.04	1.42
Wells 20 to 30 feet deep:					
Average of 14 samples	4.96	16.28	40.95	91.00	55.50
Probable error	.335	.251	1.989	5.162	.552
Error ... per cent	6.76	1.54	4.85	5.68	.995
Wells 30 to 40 feet deep:					
Average of 10 samples	4.62	17.62	38.00	92.75	55.05
Probable error	.397	.862	2.312	9.5	.74
Error ... per cent	8.60	4.89	6.08	10.23	1.34
Wells 40 to 70 feet deep:					
Average of 6 samples	2.47	12.07	16.70	35.00	53.33
Probable error	.28	.298	1.659	1.031	.596
Error ... per cent	11.33	2.47	9.93	2.95	1.12
Wells over 70 feet deep:					
Average of 4 samples	1.12	16.27	28.37	24.67	.....
Probable error	.160	.924	.939	5.854	.....
Error ... per cent	14.29	5.67	3.31	23.7	.....
Sand hills wells:					
Average of 9 samples	1.24	16.41	18.21	26.86	61.25
Probable error	.222	.587	2.32	4.05	1.07
Error ... per cent	17.9	3.57	12.73	15.06	1.75

The above table is not free from objection, since the waters of the first bottoms, second bottoms, etc., have all been grouped together. The water in the first bottoms is softer than that in the second bottoms, owing to the ease with which both the rainfall and the softer water from the river contribute to its supply. In Table 13 all wells north of the river, less than 40 feet in depth, have been classified as first-bottom, second-bottom, and upland wells, and the averages of the various groups have been taken.

TABLE 13.—*Quality of ground water in wells north of Arkansas River Valley and less than 40 feet in depth, as determined from the averages of classified samples.*

Classification.	Chlorine (parts per 100,000).	Alkalinity $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.
					° F.
First-bottom wells:					
Average of 38 samples	6.86	18.18	42.81	93.75	56.67
Probable error	.447	.809	1.672	3.318	.367
Error ... per cent	6.52	1.7	3.91	3.54	.65
Second-bottom wells:					
Average of 7 samples	4.04	18.27	47.64	89.43	52.9
Probable error	.280	.819	5.40	5.938	(a)
Error ... per cent	6.93	4.48	11.3	6.65	.....
Upland wells:					
Average of 3 samples	1.83	19.90	76.80	35.0	.....
Probable error	.216	.545	1.673	3.5	.....
Error ... per cent	11.8	2.74	2.18	10.0	.....

a One observation.

CHAPTER IV.

ORIGIN AND EXTENT OF THE UNDERFLOW.

ORIGIN.

The investigations which have been explained in the preceding pages this report indicate that the water of the Arkansas underflow has ı main source in the rainfall upon the sand hills south of the river ıd upon the bottom lands and uplands north of the river.

The average annual rainfall in the vicinity of Garden is about 20 ches. A very large portion of this passes into the level and porous ıil, so that the actual contribution to the underflow must be considable. As previously stated in this paper there is a ground water strict along the river that remains lower than the river, whether the ıme be flowing or not, in which region the rise in the ground water ter a rain is more than can be accounted for by the localized pre-ıpitation. This fact indicates not only that the underground drainge at this point is contributed to by rainfall on distant catchment reas, but that the underflow constitutes a separate drainage system hich is more than sufficient to take care of the rainfall. Determinaions made in the sandy flats south of the river at Deerfield (see Chap. I) show that the rise in the water plane, observed after a rain orm, amounts to as much as 60 per cent of the water that fell. This ıct verifies what is quite obvious to a careful observer, that there is o run-off from the lands adjacent to Arkansas River in the region nder discussion.

The total depths of the deposits of sand and gravels at Garden is ɔt known very exactly. A deep well was sunk at Garden in 1888, hich, according to a partial log printed in the local newspaper, ıowed that rock was reached at a depth of 311 feet. Every indicaon drawn from the behavior of the ground water shows that the ravels must extend to a considerable depth, so that it is safe to assume ıat the well log just referred to gives a correct notion of the depth to ıck. However, as one approaches the western boundary of Kansas, ɜd rock comes near the surface, which fact, even if no other evidence ere at hand, would show that no portion of the ground water could iginate in Colorado. The former popular belief in a Colorado source the ground water has practically disappeared, although a few settlers ill adhere to it. During the summer of 1904 one resident of Finney ounty informed the writer that the water in his well was invariably ıily after a rain storm during the preceding night in Colorado. This ırresponds to nearly passenger-train speed for the flow of ground

water. The story may be regarded as about the sole surviving gho of the numerous extravagant beliefs which were formerly curre among the settlers.

The region near Garden, Kans., is peculiarly the area proper called the High Plains. The land is level and completely covered i its natural condition with a short compact sod of buffalo grass. John son and other writers on this region have remarked the complete lac of run-off from this portion of the plains area. The precipitatio falls mostly during the summer months and is sufficient in amount t maintain a luxuriant sod, which not only protects the soil against ero sion, but prevents, by the obstruction offered by the grass, the escap

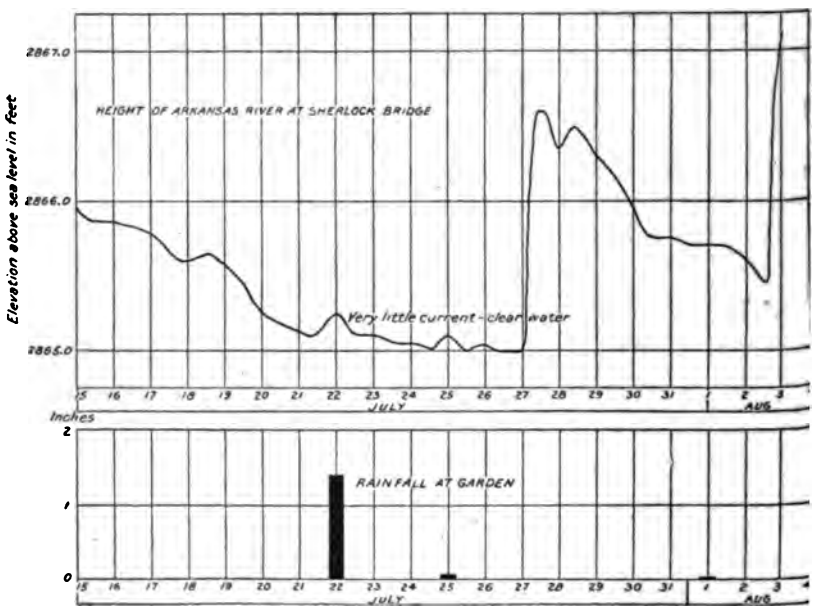
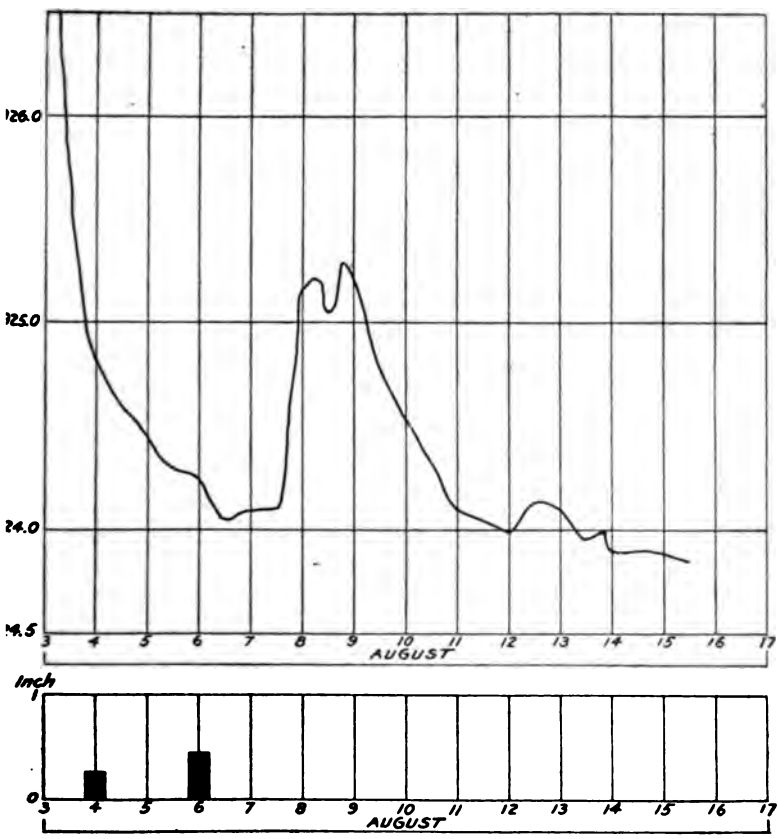


FIG. 16.—Elevation of water surface of Arkansas River at Sherlock Bridge, compared with rainf record at Garden, Kans.

of the water in flowing torrents. In consequence the rainfall is con pletely taken care of by absorption into the ground and by evaporatic and use by the vegetation. Eastward from the High Plains regic rainfall is greater, and the sod is not able to prevent the formation rills and eroded channels, so that much of the water runs off into su face streams. Westward from the High Plains district, as Colorado approached, the rainfall decreases and in consequence vegetati becomes so scant that it is not able to protect the surface of t ground from erosion even from a diminished rainfall. Hence it that both to the east and west of the High Plains there is a mark run-off, but in the plains district proper the rains are disposed of absorption.

above facts are well shown by the results previously discussed s paper. The summer of 1904 was one of unusually ample rain- n the plains, and many floods came down the river. The river carefully watched by the field party and its elevation noted. 16 and 17 show the elevation of the river at Sherlock and Deer- bridges, respectively, compared with the rainfall at Garden. A ar diagram for camp 1, near Garden, is given in fig. 10. A study ese diagrams shows practically no influence of the rainfall upon



—Elevation of water surface of Arkansas River at Deerfield Bridge, compared with rainfall record at Garden, Kans.

ream. Many of these rains extended into Colorado, where they the cause of floods that showed themselves at the camps in as many hours after the rain. Thus we have ample evidence of n-off from the country between Garden and Deerfield, and at the time have proof of a considerable run-off from the watershed d the western limit of Kansas and in Colorado.

e few instances in which small surface streams are formed near olorado line—like the plains streams known as Bear Creek and e Woman Creek—are no exception to the statement above that

TABLE 11.—*Analyses of ground water in the Arkansas Valley, western Kansas*—C

WEST OF GARDEN, KANS.—Continued.

Date.	Chlorine (parts per 100,000).	Alkalinity as $CaCO_3$ (parts per 100,000).	Degree of hardness (parts per 100,000).	Total solids (parts per 100,000).	Temperature.	Depth of well.	Location.
1904.					°F.	Feet.	
June 16	8.88	19.5	39.9	.....	.....	12	New well (camp
Do	10.62	22.5	43.7	.....	.....	14	Station 1.
July 7	.78	13.1	10.7	6	65.0	.....	Sand hills, sec. 3 S., R. 34 W.
Do	.67	13.6	11.2	6	57.0	.....	Do.
September 22	2.06	19.9	25.6	35	.....	16	Sec. 2, T. 23 S., R
1905.							
January 24	4.2	19.2	53.3	86	.....	25	Poor farm.
Do	2.1	11.4	31.1	57	.....	20	Shultz.
Do	5.1	18.0	82.0	119	.....	40	L. C. Working.
Do	4.1	20.5	31.2	102	.....	36	A. Robinson.
Do	3.4	18.1	27.9	68	.....	[a] 13	Foreman.
Do	11.4	19.2	39.3	76	.....	115	Faye.
Do	17.6	22.7	45.9	150	.....	35	M. McClurken.
Do	1.2	18.5	21.3	26	.....	[a] 30	Frank Kolbus.

GARDEN, KANS.

1904.							
September 22	0.92	14.1	25.6	16	.....	130	Atchison, Topel Santa Fe R. R
Do	.85	15.9	30.0	16	.....	110	Carter's well.
Do	3.96	20.3	69.2	80	.....	16+40	City waterworks
1905.							
January 24	1.6	18.8	29.5	42	.....	78	S. L. Leonard.

SHERLOCK, KANS.

1904.							
July 16	4.04	13.20	27.70	73.0	71.0	.....	River water.
July 22	3.85	13.90	37.90	74.0	73.0	.....	Do.
July 16	.89	21.20	13.09	27.0	63.0	8	Test well No. 6.
July 19	.50	17.50	4.64	30.0	58.5	18	Station 16.
July 16	.58	21.50	2.38	56.0	60.0	8	Test well No. 4.
July 26	1.10	17.85	26.20	42.0	56.0	26	Station 20.
July 18	3.62	16.75	27.30	35.0	57.0	22	Station 15.
July 21	2.46	21.30	28.10	55.0	56.2	36	Station 17.
July 30	4.61	19.45	44.70	83.0	65.0	10	Near station 17.
July 22	4.58	15.90	40.60	80.0	56.0	22	Station 18.
Do	4.05	15.90	42.90	78.0	57.0	14	Do.
July 23	5.20	17.45	46.30	104.0	53.0	20	Station 19.
July 16	3.47	14.65	30.00	93.0	57.7	18	Station 14.
Do	5.10	15.75	31.10	97.0	55.0	22	Do.
July 15	5.18	15.50	.....	107.0	54.0	18	Station 13.
July 27	4.97	15.25	48.5	96.0	55.5	28	Station 21.
Do	4.90	16.25	50.6	97.0	57.5	28	Station 22.
July 19	.96	16.85	20.0	21.0	.....	.....	Sec. 30, T. 24 S., R
Do	.17	19.00	25.9	37.0	.....	.....	Sec. 20, T. 24 S., R
September 22	2.24	21.30	29.9	44.0	.....	40	Sec. 30, T. 22 S., R

[a] To water.

CHAPTER V.

SUMMARY OF TESTS OF SMALL PUMPING PLANTS IN THE ARKANSAS VALLEY.

GENERAL RESULTS.

Table 14 shows the results of tests of a number of pumping plants used for irrigation in Arkansas Valley between Garden and Lakin, Kans. Most of the entries in the table explain themselves.

The fuel used in most of the plants is gasoline, the current price of which during the summer of 1904 was 22 cents a gallon, a cost that is almost prohibitive, even when pumping water from the most excellent wells found in the valley.

TABLE 14.—*Tests of small pumping plants, Arkansas Valley, Kansas.*

1	2	3	4	5	6	7
Owner of plant.	Location.	Kind of pump.	Horsepower of engine.	Fuel used.	Price of fuel per gallon.	Total lift.
						Feet.
D. H. Logan	Garden, Kans.	No. 3 centrifugal	6	Gasoline	$0.22	22.1
Mrs. M. Richter	do	Menge	10	do	.20	15.5
C. E. Sexton	do	2 vertical 6 by 16 cylinder.	1½	do	.22	15.06
Nathan Fulmer	Lakin, Kans	Chain and bucket	7	do	.21	17.0
J. M. Root	do	do	2½	do	.22	15.8
King Bros	Garden, Kans.	No. 4 centrifugal	14			63.0
Waterworks	do	2 duplex steam				
I. L. Diesem	do	No. 4 centrifugal	10	Gasoline	.12½	22.13
L. E. Smith	do	No. 3 centrifugal	6	do	.12½	17.60
H. B. Holcomb	Sherlock, Kans	No. 14 centrifugal	80	Coal	[a] 4.00	23.0
H. S. Kipp	Garden, Kans.	2 horizontal 5 by 5 cylinders.	3½	Gasoline	.12½	21.7
J. R. McKinney	do	No. 4 centrifugal	5	do	.12½	21.47

[a] Price per ton.

TABLE 14.—*Tests of small pumping plants, Arkansas Valley, Kansas*—Continued.

1	8	9	10	11	12	13	14
Owner of plant.	Distance water is lowered	Yield of well per minute.	Specific capacity of well per minute.	Area of percolating or strainer surface.	Specific capacity per square foot of strainer per minute.	Cost of fuel per acre-foot of water.	Cost of fuel per 1,000 foot-gallons.
	Feet.	*Gallons.*	*Gallons.*	*Sq. feet.*	*Gallons.*		*Cents.*
D. H. Logan	6.85	272	42.2	107.0	0.394	$2.93	[illegible]
Mrs. M. Richter	5.3	394	73.0	266.5	.27	2.90	[illegible]
C. E. Sexton	3.0	91	30.3	57.2	.53	3.75	[illegible]
Nathan Fulmer	6.35	540	85.0	334.0	.254	1.37	[illegible]
J. M. Root	4.16	215	51.7	210.0	.246	2.78	[illegible]
King Bros	20.3	183	9.0	85.0	.106	.....	.....
Waterworks	5.48	290	77.0	247.0	.31	.....	.....
I. L. Diesem	6.72	363	54.0	151.0	.356	2.10	[illegible]
L. E. Smith	2.16	198	91.6	70.7	1.290	1.67	[illegible]
H. B. Holcomb	9.60	2,300	240.0	1,876.0	.128	[a] .85	[illegible]
H. S. Kipp	2.83	96	34.0	45.3	.75	1.09	[illegible]
J. R. McKinney	8.39	420	50.0	116.0	.42	1.20	[illegible]

[a] Including cost of labor and lubricating oil.

SPECIFIC CAPACITY.

The numbers in column 10 express the readiness with which the well furnishes water to the pump. The numbers in each case were found by dividing the numbers in column 9 by the corresponding numbers in column 8; these numbers, therefore, express the amount of water the well would furnish if the water level was lowered but 1 foot. These numbers constitute what the writer has called the "specific capacity" of the well, and are large in the case of a good well and small in the case of a poor well.

The water-bearing gravels are usually from 9 to 15 feet below the surface of the ground, and good wells can be very cheaply constructed. There is no quicksand or hardpan or other troublesome material above the water-bearing gravels. The well tubes or strainers are usually 12 to 20 inches in diameter, and are made of slotted galvanized iron. For the most part the wells are of the very best design and possess a remarkably high specific capacity; the writer knows of few places where better ones can be constructed.

The usual construction consists of a dug well, 6 to 10 feet in diameter, excavated several feet below the level of ground water, with a number of "feeders" or tubular wells penetrating the bottom of the well. No better construction can be suggested for small plants. The only modification in detail that seems likely to better the present excellent results would be the use of galvanized-iron strainers with larger slots than are at present in use. This would be practicable at some of the wells. Heavy pumping would remove much of the fine material that now remains in contact with the present well strainers.

In column 12 there are given the same magnitudes as are expressed in column 10, reduced in each case to 1 square foot of well strainer. The numbers in this column express, therefore, the amount of water in gallons per minute furnished by 1 square foot of well strainer under a head of 1 foot of water. They are a numerical expression of the degree of coarseness of the material in which the well is placed.

These numbers are almost the same for all of the well plants, when proper allowance is made for difference in construction. At the Richter, Fulmer, and Root plants, there are large dug wells with several feeders in the bottom. The numerous feeders interfere with each other somewhat, keeping the specific capacity lower than it would otherwise be. At the Logan and Sexton plants the construction is different. The Logan well is constructed of 20-inch casing, through the bottom of which are two 4-inch feeders extending 26 feet below the bottom of the 20-inch casing. The 20-inch casing is perforated for 10 feet at the bottom. At the Sexton plant there is a 12-inch well 22 feet deep, and a 10-inch well 31 feet deep, both perforated 10 feet from the bottom.

COST OF PUMPING.

While the cost of water at these various pumping plants may at first glance seem high, and the results not especially encouraging, yet a more careful inspection shows that the facts are really highly favorable. It must be remembered that the cost of pumping is based upon a 22-cent price of gasoline. This price is almost prohibitive, but fortunately there exist several possible ways of cutting down very materially the cost of power, and on this point the following suggestions are offered:

In the first place, the cost of pumping can be reduced by the use of crude oil in place of the gasoline. Crude oil from Kansas fields should be laid down at Garden at from 3 to 4 cents a gallon. The crude oil requires a special device, which must be used in connection with the gasoline engine, called a generator, in which the crude oil, or part of it, is converted into a gas before it is led into the engine cylinder. By the use of such a generator the cost of fuel can be lowered to a point about equivalent to a 5 cents a gallon price for gasoline. The crude-oil generators will work best on engines of 12 to 30 horsepower.

If plants of from 20 to 50 horsepower are constructed, as I believe will inevitably be the case in the near future, the cheapest power will probably be found in the use of coal in small gas-producer plants in connection with gas engines.[a] These small gas-producer plants are largely automatic in action and can be operated by anyone. With hard coal or coke or charcoal at $8 per ton, the cost of power would be less

[a] See test of producer-gas plant, Chapter VI.

than one-half cent per horsepower for one hour, or only one-fifth o the cost of power from gasoline at 22 cents a gallon. The writer antici pates no difficulty, therefore, in keeping the cost of water below 60 t 75 cents an acre-foot for fuel, or below $1.25 to $1.50 per acre-foot fo total expense. Hundreds of such plants have been put in use in Eng land during the past ten or more years, and they are in charge o unskilled labor. These gas-producer plants are used in England for great variety of purposes, such as power for agricultural machinery and for small electric-light plants for country estates, etc. They ar used in as small units as 5 horsepower.

In this country the producer-gas plants have been in use for severa years, and at the present moment they are fast taking the place o steam power in new plants. The cost of a producer plant and ga engine is about the same as the cost of a steam engine and boiler o same size when everything is included, but the cost of power fro the producer-gas plant is very much less than that obtained from sma steam engines.

In producer plants, ranging upward from 100 horsepower, a style o plant may be installed in which soft coal or lignite may be successfull used. This still further cuts down the cost of power. In fact, larg plants of this type furnish the cheapest artificial power that has y been devised. The saving is not only in fuel, but also in labor, as o man is capable of running a 300-horsepower plant.

That part of the operating expense which is properly chargeable fuel cost can be accurately determined. Column 13, Table 14, express the cost per acre-foot of water recovered. In column 14 is given t cost of fuel for lifting 1,000 gallons of water 1 foot. For the purpo of comparison, these results are expressed in fractional parts of a cen It should be noted that the cost given in the table is based upon 22-cent price for gasoline. There is no doubt but that producer-g plants in moderate-sized units would enable irrigation by pumping i the bottom lands of Arkansas River to be highly profitable.

No allowance has been made for interest, depreciation, and labo These expenses, if included, would about double the cost per acre-foo

CHAPTER VI.

DETAILS OF TESTS OF PUMPING PLANTS.

TEST OF PUMPING PLANT OF D. H. LOGAN, GARDEN, KANS.

This plant is located in the northeast corner of sec. 13, R. 33 W., T. 24 S., and is in the northwest corner of the city of Garden. The outfit consists of a 6-horsepower Fairbanks, Morse & Co. horizontal gasoline engine connected by a belt to a No. 3 centrifugal pump. The well is constructed of 20-inch galvanized-iron casing 32 feet long, perforated 10 feet up from the bottom, inside of which are two 4-inch feeders 28 feet long, perforated their entire length, and extending 26 feet below the bottom of the 20-inch casing, making a total depth of 58 feet. The pump has been in operation since April, 1902, and the engine since April, 1903. The water was measured by the use of a fully contracted weir with a length of crest of 0.66 foot.

The engine was started at 9 o'clock and the weir was ready for water at about 10.30. The water was turned on weir and the head read until it became constant at 1 p. m. In order to determine the expense of pumping, all of the gasoline was used out of the reservoir, then 1 gallon was poured in and the length of the run noted to be one hour and thirty-two minutes, or two-thirds gallon per hour. As the engine is a 6-horsepower one, this equals 0.111 gallon, or 0.445 quart of gasoline per horsepower hour.

The average corrected head on the weir was found to be 0.440 foot. Using weir formula

$$q = c\,\tfrac{2}{3}\sqrt{2g}\,b\,H^{\frac{3}{2}},$$

where $b=0.66$, whence $c=0.592$, the discharge is found to be

$$q=0.6045 \text{ second-foot}=272 \text{ gallons per minute.}$$

Data of Logan pumping plant, Garden, Kans.

	Feet.
Average depth to water while pumping	18.6
Normal depth to water	11.75
Amount lowered by pumping	6.85
Elevation of well platform	2,835.26
Distance water was raised above platform	3.5
Lift, or total distance water was raised	22.1

Total area of well strainer, 107 square feet.

The fuel cost of pumping was, therefore, 0.9 cent per 1,000 gallons of water recovered, or $2.93 per acre-foot. The cost of 1,000 foot-gallons (1,000 gallons raised 1 foot) was, therefore, 0.0406 cent, or one twenty-fifth cent.

The specific capacity of the well is 42.2 gallons a minute, or 0.394 gallon for each square foot of well strainer.

The engine ran at a speed of 350 revolutions a minute, exploding 143 times a minute. The diameter of engine pulley is 16 inches and of pump pulley 10 inches. This gives a speed of 560 revolutions a minute to the pump.

The size of the pond was 40 feet by 60 feet, mostly covered with a green scum, which would prevent evaporation. As to seepage, the pond falls 8 inches in twelve hours at night. The pond being 2,400 square feet in area, the observed seepage represents a loss of 16.68 gallons per minute, which should be added to the capacity of pump and well, but not to the effective capacity for Mr. Logan.

There is a windmill at a well 20 feet north of the one pumped by the gasoline engine—a 12-foot airometer connected to a 10-inch pump of 12-inch stroke. After the weir measurements were completed the windmill was thrown into gear. There was a brisk wind from the south and the pump threw a good quantity of water, but no appreciable lowering of the water in the gasoline-engine well 20 feet away was detected. The rise of the water in the well was obtained twice.

Below are the two sets of observations:

Rise of water after cessation of pumping in Logan well, Garden, Kans.

FIRST TRIAL—WINDMILL NOT RUNNING.

Time.	Depth to water.	Time.	Depth to water.
	Feet.		*Feet.*
55 seconds	[a] 18.60	2 minutes and 8 seconds	12.25
1 minute and 5 seconds	16.05	2 minutes and 22 seconds	12.25
1 minute and 20 seconds	14.55	2 minutes and 33 seconds	12.25
1 minute and 37 seconds	12.95	2 minutes and 48 seconds	12.15
1 minute and 55 seconds	12.50		

SECOND TRIAL—WINDMILL RUNNING.

24 minutes and 30 seconds	(a)	25 minutes and 48 seconds	12.55
24 minutes and 35 seconds	18.0	26 minutes	12.45
24 minutes and 45 seconds	16.5	26 minutes and 23 seconds	12.25
24 minutes and 48 seconds	14.35	26 minutes and 58 seconds	12.25
25 minutes and 10 seconds	13.10	27 minutes and 15 seconds	12.25
25 minutes and 26 seconds	12.90	27 minutes and 30 seconds	12.25
25 minutes and 38 seconds	12.55		

[a] Stopped pumping.

The curves showing the rate of rise of water in the Logan well after pumping ceased are given as curves 1 and 2 in fig. 18. Curve 2 is the one which was produced when the windmill was pumping from a well 20 feet away. The comparison of this curve with curve 1, which was produced when the neighboring well was not used, is very interesting, showing, as it does, a less rapid rise when the neighboring well was in use. To find the specific capacity for the Logan well from these curves we must substitute the values of the various constants in the formula

$$c=17.25\,\frac{A}{t}\log\frac{H}{h}\text{ gallons per minute.}$$

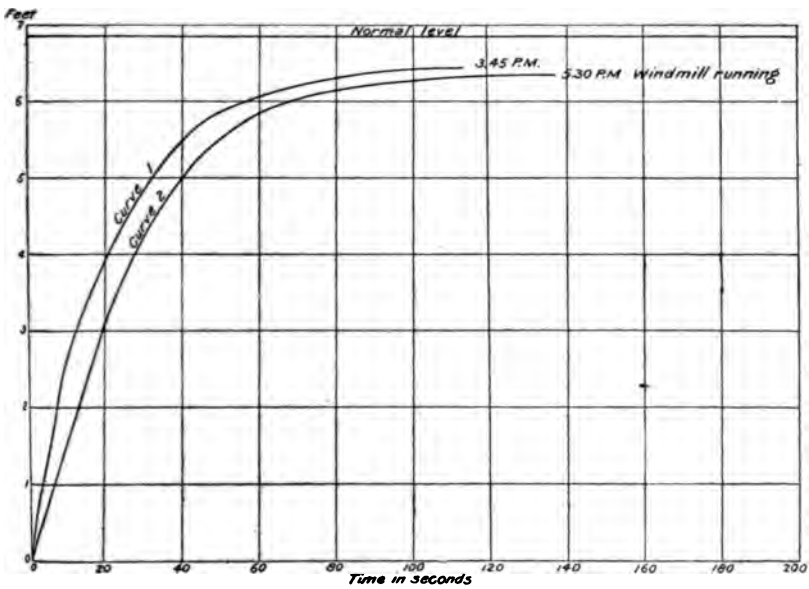


Fig. 18.—Rising curves for Logan well. Curve 2 taken when neighboring well was being pumped by windmill. Curve 1 taken when windmill was shut off.

The value of the area, A, of cross section of the well casing is 2.17 square feet, and H, the amount the water is lowered by the pump, is 6.85 feet. The amount of depression, h, of the water level below the natural level at any time can then be selected from the curve, and the specific capacity readily computed. If t be taken to be 40 seconds, or $\frac{2}{3}$ of a minute, h will be found from the curve to be equal to $6.85-5.5=1.35$ feet, hence

$$c=17.25\times\tfrac{3}{2}\times 2.17\times\log\left(\frac{6.85}{1.35}\right)\text{ gallons per minute}=39.5\text{ gallons per minute.}$$

The yield of the well for the maximum depression, 6.85 feet, must then be

$$6.85\times 39.5=270\text{ gallons per minute.}$$

The curve of rise of water forms one of the best methods of determining the yield of a well. Such curves can readily be obtained. Well data should always include measurements of the amount of lowering of the water surface by the pumps, and it is only necessary to continue these measurements after the pumps have stopped to secure sufficient data to estimate the specific capacity and total yield of the well. This avoids the necessity of constructing a weir or other method of measuring the water discharge. The accuracy is sufficiently great for the purpose for which such data are used. The method can be used only in cases where an internal suction pipe extends into the well casing with sufficient room around it to permit a sounder to be lowered to the water surface. If there is no foot valve or other means for preventing the water from returning to the well after pumping ceases, the rising curve may still be used for the determination of the specific capacity, provided that only the portion of the curve be used which was formed after the water had completely returned to the well from the pump.

TEST OF THE RICHTER PUMPING PLANT, NEAR GARDEN, KANS.

This plant is located in the northwest corner of SW. ¼ sec. 14, R. 33 W., T. 24 S. The upper part of this well is cased with part of the old standpipe from Garden. The casing is 10 feet in diameter and extends down 20 feet. In the bottom of this part of the well are placed four 8-inch galvanized-iron feeders, arranged symmetrically about the center; each feeder is 25 feet long, perforated its entire length, and extends about 2½ feet above the bottom of the large part of the well.

The pump used is a Menge pump, which operates on the principle of a screw propeller of a steamship. It bores the water out and up a square wooden penstock or pump shaft. There are two of these propellers mounted one above the other on vertical iron shaft inside the penstock. The top of the iron shaft carries the belt pulley and has a shoulder bearing which takes the thrust of the pump as a pull above. This pump is made in New Orleans.

The pump is run by a 10-horsepower Otto gasoline engine, which runs at a speed of 300 revolutions per minute. The circumference of the drive pulley is 5.25 feet, and of the driven pulley 2.65 feet, making the pump run at 595 revolutions per minute. The screws are boxed up and under water when the pump is not in operation. A small pond was constructed at the end of the discharge trough and a fully contracted rectangular weir of length of crest of 1.2 feet was used to measure the discharge. The measurements for head were taken 6 feet away from the weir, and boards were interposed between

charge trough and weir to cut down the velocity, which might › give erroneous results. The average corrected head on the as 0.371 foot. Using the weir formula

$$q = c\tfrac{2}{3}\sqrt{2\,g}\;b\;H^{\frac{3}{2}}$$

ting c from Merriman's tables as 0.603,

$$q = 0.876 \text{ second-foot} = 394 \text{ gallons per minute.}$$

g a small Price acoustic water meter in the discharge trough, ısuring the velocity at different places and also by integrating, ıcharge was found to be 0.76 second-foot, or 342 gallons per . The water in the flume was so shallow that this determina- of little value. By putting chips in the discharge trough and ıg the time with a stop watch, the surface velocity was found .565 feet per second. This number multiplied by 0.8 gives an e velocity of 1.25 feet per second and a discharge of 0.884 -foot, or 397 gallons per minute.

attempt was made to determine the amount of gasoline used. ıervoir was filled full and the engine run for 1 hour and 36 min- r 1.6 hours. All the gasoline we had, 9¼ quarts, did not then tank. This was at noon, July 6. On the morning of July 7, rts were required to completely fill the reservoir, a total of 18¾ or 37½ pints for the run of 1.6 hours for a 10-horsepower . The makers claim their engines use one pint per horse- hour. This would require in this case 16 pints, or less than f what was actually measured, if the engine developed its full ower. A leak in the tank or feed pipe is clearly indicated, so ıount, while being of value to the owner of the plant, is value- far as comparative cost of pumping is concerned.

observations of the rising curve were obtained which plot well er. The lower part of the curve is not accurate, because of the in the penstock dropping back into the well when pumping

Data of Richter pumping plant, near Garden, Kans.

	Feet.
›n of the ground at well	2,846.0
› elevation of water in well	2,836.8
› elevation of water in well when pumping	2,831.5
on of discharge from penstock	2,847.0
ift	15.5
e amount water is lowered by the pump	5.3

ber of explosions of engine, 126.5 per minute.

l area of surface of well strainers and all percolating surfaces, 226.5 square feet.

The curves of rise for this well were obtained on two different occasions and are shown as curves 1 and 2 in fig. 19. They plot together very well. To find the specific capacity of the well from the curve, we note the following values of the constants in the formula for specific capacity:

$$c=17.25\,\frac{A}{t}\log\frac{H}{h}\text{ gallons per minute.}$$

The area, A, of cross section of the well casing, less the amount occupied by obstructions, is 76.79 square feet. The amount, H, that the water is lowered by the pump is 5.3 feet. The amount of depression, h, of the water surface below the natural level at any time can be selected from the curve. From the curve, at the close of ten minutes, h equals 5.3 less 4, or 1.3 feet.

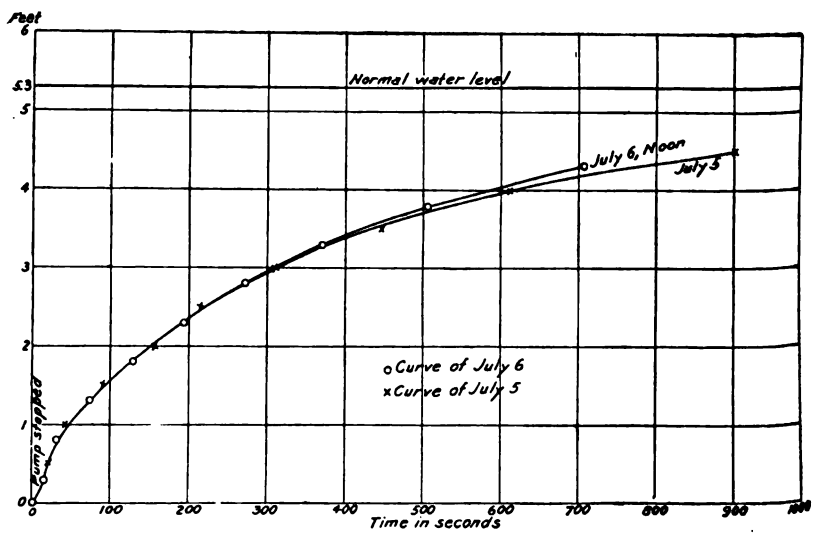


FIG. 19.—Rising curves for Richter well, near Garden, Kans.

Hence the specific capacity

$$c=17.25\times\frac{76.79}{10}\log\frac{5.3}{1.3}=81\text{ gallons per minute.}$$

Multiplying by 5.3, the head under which pumping took place, the total yield of the well is $81\times5.3=430$ gallons per minute.

The above determination of the specific capacity is inaccurate, since the first portion of the rising curve does not show the true rate of rise of water in the well. The penstock of the propeller pump holds 37.7 cubic feet of water, which immediately returns to the well when the pump is stopped. This amount of water is sufficient of itself to raise the level in the well by 0.465 foot. For this reason, only that portion of the rising curve should be used which is not influenced by

returning water from the penstock. Thus, if we use that part of curve from $t=100$ seconds to $t=600$ seconds, we will eliminate inaccurate portion. Making this modification, the data are ıged to

$$H=3.75 \text{ feet}; \ h=1.30 \text{ feet}; \ t=8\tfrac{1}{3} \text{ minutes}.$$

ıputing the specific capacity on this basis, we obtain

$$c=73 \text{ gallons a minute}.$$

ltiplying this by 5.3, the total estimated yield is 388 gallons a min- which checks remarkably with 394 gallons a minute obtained.

he area of the strainer and bottom of the well is 266.5 square feet. above specific capacity divided by 266.5 gives 0.341 gallon per ute as the specific capacity per square foot of percolating surface.

'he engine ran at a speed of 300 revolutions and exploded 125 times minute. This would indicate that it was working at about 83 per t of its rated capacity. Assuming that such was the case, and that ould then use 83 per cent of the fuel necessary to run it at its full ed power (10 horsepower), we have 8.3 pints as the probable amount gasoline used per hour by the engine during the test. This, at 20 ıts per gallon, would make a cost of 21 cents per hour. This umption makes the cost of water 0.89 cent per 1,000 gallons, $2.90 r acre-foot, and one-seventeenth cent per 1,000 foot-gallons.

ST OF PUMPING PLANT OF C. E. SEXTON, NEAR GARDEN, KANS.

This plant is located at about the center of sec. 13, R. 33 W., 24 S., and is 1 mile west of Garden. It consists of two pumps of -inch stroke, with 6-inch pistons, connected to a walking beam and iven by 1½-horsepower Fairbanks, Morse & Co. vertical gasoline gine. The east well has a 12-inch casing 22 feet deep, and the west ll a 10-inch casing 31 feet deep, both casings being perforated for a tance of 10 feet up from the bottom. The pump rods are 2 by 4 ıbers.

The two pumps discharge into an artificial pond or reservoir, and flow was measured with a weir at the outlet of the reservoir. e weir was fully contracted with a length of crest of 0.66 foot.

The height of water on the weir was measured by placing a stick the head of the nail and marking the water line on the stick with encil, then measuring with a pocket tape; in the absence of a hook ge this was the best method that suggested itself.

The weir heights taken as a measure of the discharge of the pump those obtained after the water level in the reservoir had become tionary, as indicated by an absence of systematic variation of the

weir heights. As evaporation would make the results too small, the following data are important:

The size of reservoir is 50 feet by 90 feet, or 4,500 square feet; trees border the north and south sides, with high grass along the banks; brisk wind was blowing from southwest; temperature of air was 80°, temperature of water, 52°; there was sunshine until about 3 p. m., when it became cloudy and the wind moderated.

The east well threw a much smaller stream than the west well, probably due to a leak in the suction pipe, and consequent pumping of air. No air was pumped by the west pump.

Measurements to the water surface in the east well were made at five-minute intervals, but no soundings were obtained in the west well. The number of strokes of each pump averaged 24.5 per minute during the test; the number of explosions of the gasoline engine averaged 106.2 per minute. The battery used with the engine not working satisfactorily, a gasoline torch was used for ignition. Gage readings of distance to water in well were made downward from a point on the well platform whose elevation above sea level was 2,836.69.

Data of Sexton pumping plant, near Garden, Kans.

	Feet.
Distance to water when level is normal	8.8
Distance to water when pumping	11.86
Amount water level was lowered	3.06
Elevation	2,827.9
Distance water was raised above point on platform	3.2
Total distance water was raised (11.86+3.2)	15.06

Total area of well strainers, 57.2 square feet.

The reservoir has been in use for some time and the seepage was probably quite small, a small enough per cent to be negligible. There was no leakage around the weir, or elsewhere.

The gasoline tank was filled at the start, and when the run was completed the amount needed to refill was measured, thus getting the amount used by the engine, which was 11 quarts for a run of 9 hours and 37 minutes, or 1.14 quarts per hour, making a trifle over three-fourths quart per horsepower hour. The average corrected weir height was 0.206 foot.

Using the formula for a contracted weir

$$q = c\tfrac{2}{3}\sqrt{2g}\, b\, H^{\frac{3}{2}},$$

and taking from Merriman's Hydraulics the value of the constant c for $b=0.66$ and $H=0.206$ as 0.611, we have for the discharge

$$q = 0.202 \text{ second-foot}, = 91 \text{ gallons per minute.}$$

With gasoline at 22 cents per gallon, or 5½ cents per quart, the expense of an hour's run, not counting gasoline used for ignition tube, is

5 per hour, or $0.0115 per thousand gallons of water pumped, 75 per acre-foot. The lift being 15.06 feet, the cost per 1,000 llons is 0.076 cent, or about one-thirteenth cent per 1,000 gal-ised one foot.

uly 8 the rise of water in the east well was taken by means of pine board stuck down between the casing and pump. The ls of time were measured with a stop watch. The pine strip wered into the well until the water was reached, after which the was drawn up, the wet line marked, the time recorded, and the replaced, the observations being repeated as fast as possible. stances marked on the strip were measured later.

ise of water after cessation of pumping in Sexton well, near Garden, Kans.

Time.	Rise.
	Feet.
.....	0.46
ds.....	2.44
ds.....	2.92
.....	3.01
ds.....	3.02
ds.....	3.03

rising curve plotted from these data was of little use in deter- the specific capacity of the wells, both on account of an wn amount of water returned to the well by leakage of the and because of the unknown amount of lowering of the water west well.

OF PUMPING PLANT OF NATHAN FULMER, LAKIN, KANS.

plant is in the center of NE. ¼ sec. 10, R. 36 W., T. 25 S., ey County, 3 miles south of Lakin, Kans. The well consists of len casing, 6 feet in diameter and 10 feet deep, sunk with the sh with the surface of the ground. Inside of this cylindrical and extending 9½ feet below the bottom of it is a tapered wooden g 10 feet long, 4 feet in diameter at the top, and 5 feet in er at the bottom. This curb was given the tapering form in o lessen the friction on the sides in sinking the well. The total of the two large curbs is 19½ feet. Arranged in a circle in the of the main well, about 5 inches from the edge, are 7 feeders. f these feeders are 7 inches and 3 are 8 inches in diameter. The of each feeder is 23 feet 4 inches. The feeders extend down to 3 or 4 inches of an underlying clay or silt and 8 inches above tom of the large well. The total depth of the well is 42 feet. ders are made of No. 20 galvanized sheet iron with three-eighths- rforations arranged in circles from three-fourths of an inch ches apart.

The material encountered in sinking the well, according to M Fulmer, was, first, 4 feet of clay, then sand, which became coar with the depth. The bottom stratum consists of a mixture of fi sand and gravel, some of the latter being the size of a hen's eg Water was found at a depth of 8 feet.

A local make of chain and bucket pump, known as the Pittm pump, is used in this well. It consists of an upper shaft and su merged lower shaft around which run the two sprocket chains which are attached the galvanized iron buckets, each with a capaci of 12.5 gallons. The buckets, 33 in number, are hung between t chains and are of such shape that when they come over at the top the circuit they discharge the water readily into the discharge troug allowing very little to run back into the well. To aid in starting t water down the trough a number of horizontal guide vanes are plac therein with a slope away from the descending buckets in such a w that the water is started down the trough with very little splashi back into the well. These pumps are of a recent design, and are ma in Kearney County. There are three such pumps in operation, o run by a windmill near Garden, and one owned by Mr. Root, a test which is described in this report (pp. 70-73).

The power is supplied through the proper gearing by a Ho gasoline engine, built by the Middletown Machine Company, whi develops about 7 horsepower at 285 revolutions per minute. T engine is cooled by water taken from the discharge trough. T supply of gasoline is put in a rectangular sheet-iron tank, 2.4 feet l 2.6 feet by 1 foot high, which is placed in the ground outside the engi house. The ratio of the gearing between the engine and bucket cha is such that 175½ revolutions of the engine produce 1 revolution the bucket chain, or 5¼ revolutions of the engine to each buck discharge.

The discharge trough empties into a reservoir from which the see age is quite rapid. As there was no chance to put a weir betwe the pump and the reservoir, and since one placed at the outfall of t reservoir would measure only a portion of the water entering t reservoir, the amount of water pumped was measured by counti the number of revolutions of the bucket chain and computing t capacity of several buckets to secure an average value. The avera capacity was found to be 12.52 gallons. The computed dischar obtained by counting the revolutions of the bucket chain and noti the time, was 561 gallons per minute. It was estimated that t buckets lacked about 0.05 foot of being full, this being about 4 p cent of the measured capacity of the buckets. Also, during the r 22 buckets came up empty, caused by the failure of the valve in t bottom to work, which amounts to a loss of one-fourth of 1 per c of the total discharge. Reducing the observed 561 gallons by 4 p

ves 540 gallons per minute as the corrected discharge of the The water level was lowered 6.35 feet below the normal. The he discharge trough was 17 feet. The engine ran at 240 revo- and averaged 64 explosions per minute.

amount of gasoline used was determined by measuring the ›f gasoline in the tank at intervals and noting the time at each ement; then by plotting a curve the average rate per hour of ıg of the gasoline in the tank was obtained, and, the horizontal ɔction of the tank being known, the amount of gasoline used ır was computed to be 0.65 gallon. The cost of gasoline was 's per gallon in barrel lots, making the expense of running the

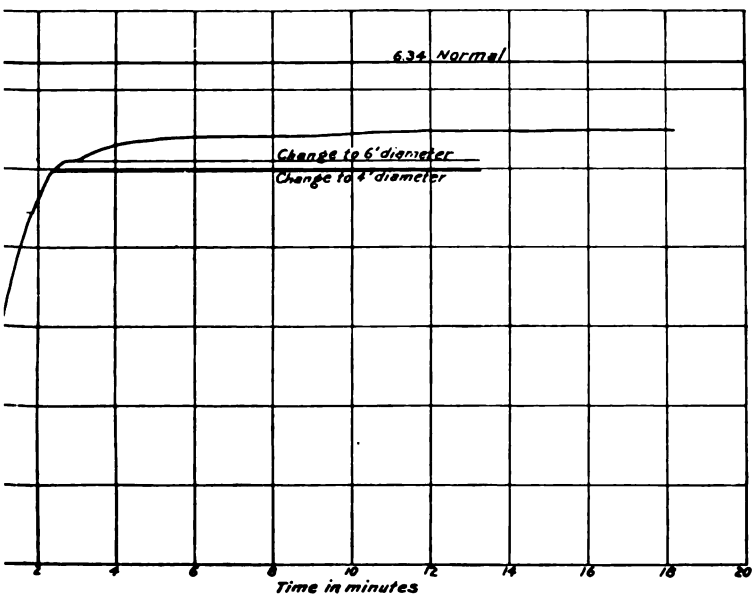


FIG. 20.—Rising curve for the Fulmer well, Lakin, Kans.

13.65 cents per hour. The cost of water per acre-foot was ›re $1.37. The cost of water per 1,000 gallons was 0.42 cent, : cost per 1,000 foot-gallons was one-fortieth of a cent.

ɜervoir 100 feet wide by 240 feet long is used in connection with nt. This reservoir was made by digging out the inside and he material to form the banks. This produced a very porous and much trouble has been experienced from seepage. To · this the bottom was puddled thoroughly by plowing and har-, then putting in chaff and straw and herding cattle and horses ›ottom for several days, but the surface of the water still drops : inches per day.

ɔbservation of the rising curve of this well was made (fig. 20). ll be noticed that there is an irregularity in the curve correspond- ı depth of about 1½ feet below the normal water level, caused

by the sudden change in cross section from 12½ square feet to 28½ square feet at the top of the lower casing. From the rising curve the specific capacity may be obtained from the following formula:

$$c=17.25\,\frac{A}{t}\log\frac{H}{h}$$

At a point 4 feet above lowest position of water level the average area A of the well from 0 to this point is 17 square feet. $t=1.6$ minutes; $H=6.35$ feet; $h=2.35$ feet.

Then $c=80$ gallons per minute. This, multiplied by 6.35, the amount the water was lowered by pumping, gives 508 gallons, which is within 6 per cent of the observed discharge.

The total area of percolating surface, 7 feeders, and the bottom of the well, is 334 square feet. The above specific capacity divided by 334 gives 0.24 gallon per minute per square foot of percolating area.

The amount of water recovered can not be increased without lowering the pump, as a glance at the diagram will show, the water level being now lowered slightly below the lower shaft.

The Fulmer plant was installed in the spring of 1903 and has been in operation since April of that year. The cost of the entire plant is as follows:

Cost of Fulmer plant, Lakin, Kans.

	Cost of material.	Labor.		Total cost.
		Time, in days.	Cost.	
Well:				
Material and lumber	$18.50	[a] 3	$6.00	$24.50
Digging	.....	[a] 45	90.00	90.00
Seven feeders at $8.40 (24 feet each, at 35 cents a foot)	58.80	.....	.....	58.80
Reservoir, man and team, at $3.50 a day	.....	40	140.00	140.00
Pump, made by Mr. Fulmer, market price about	260.00	.....	.....	260.00
Engine:				
Cost in Kansas City	328.50	.....	.....	347.12
Freight	18.62			
Shed, 8 by 22 by 7 feet	35.00	[a] 5	10.00	45.00
Incidentals	.....	.....	.....	34.38
Total cost	719.42	.....	246.00	1,000.00

[a] Labor, $2 a day.

Mr. Fulmer uses water from the south-side ditch, and only about 15 acres of cantaloupes and fruit trees are irrigated. The capacity of the plant is about 100 acres.

TEST OF PUMPING PLANT OF J. M. ROOT, LAKIN, KANS.

This plant is located at the southeast corner of northwest ¼ sec. 4, R. 36 W., T. 25 S., Kearney County, 3 miles southwest of Lakin, Kans.

The well consists of a wooden casing, 6 feet in diameter and 12 feet long, sunk with the top flush with the ground. Inside of and below

ı 10-foot casing, 4½ feet in diameter at the top and 5½ feet at tom, sunk until the top is 2 feet above the bottom of the upper making the total depth of the main well 20 feet. In the bot- this main well are sunk 5 feeders in a circle about 10 inches e edge of the lower casing. The feeders are 8 inches in diam- ro of them are 24 feet long and three are 18 feet long. The feeders project 2 feet above the bottom, while the 18-foot project only 1 foot. These feeders are made of No. 20 gal- iron, and the perforations are the same as in Fulmer's well, sly described.

naterial encountered in sinking the well was, first, about 1 foot , then about 17 feet of black dirt, followed by 1 foot of yellow d 2 feet of sandy clay. There is no record of the material ered in sinking the feeders.

Pittman pump is used in this well and is of the same pattern as ıcribed in connection with the Fulmer plant. The buckets are , having a capacity of 6.3 gallons, and the bucket chain has or 40 buckets, 24 of which were in place at the time of the The vacant places were left at regular intervals around the ıut the effect was to give the chain a swinging motion, which the slopping out of a great deal of water. The valves in the ı of the buckets also leaked excessively.

r is furnished by a vertical 2½-horsepower two-cycle Weber engine with throttle governor, built by the Weber Gas and e Engine Company, Kansas City, Mo. The engine is cooled ıall tank and exploded by an autosparker. The ratio of the between the engine and the bucket chain is such that 257 ions of the drive wheel produce 1 revolution of the bucket ır 6.4 revolutions of the engine to each bucket raised, if the are all on the chain.

is no reservoir used with this plant. The discharge was d with a fully contracted weir, with a length of crest of 1 The average head observed was 0.2805 foot, giving the follow- harge by the Francis formula:

$$
\begin{aligned}
q &= 3.33\,(b - 0.2\,H)\,H^{\frac{3}{2}} \\
&= 3.33\,(1.0 - 0.056)\,0.2805^{\frac{3}{2}} \\
&= 3.33 \times 0.944 \times 0.1485 \\
&= 0.4675 \text{ second-foot} \\
&= 210 \text{ gallons per minute.}
\end{aligned}
$$

ıe formula given by Merriman for fully contracted weir of ıf crest of 1 foot the discharge is computed to be 218 gallons per

The following computations are based on a discharge of 215 per minute: As the water level was lowered 4.16 feet the specific is 51.7 gallons per minute. The lift was 15.8 feet. The

engine averaged 488 revolutions per minute, exploding at ever lution.

The amount of gasoline used for a three-hour run was exa quarts, or at the rate of 0.5 gallon per hour. This gasoline cents per gallon, making the cost of fuel 11 cents per hour. Tl of water is 0.855 cent per 1,000 gallons, $2.78 per acre-foot, an nineteenth cent per 1,000 foot-gallons. The lack of economy plant is in the engine, which is old and in poor condition, and buckets, the valves of which leak badly. Also the water wa ered so far that the buckets did not start up full, and the sw motion of the chain spilled a great deal. The owner has neve able to keep the plant running for more than half an hour at a and it took as long to put the plant in order as it did to make th

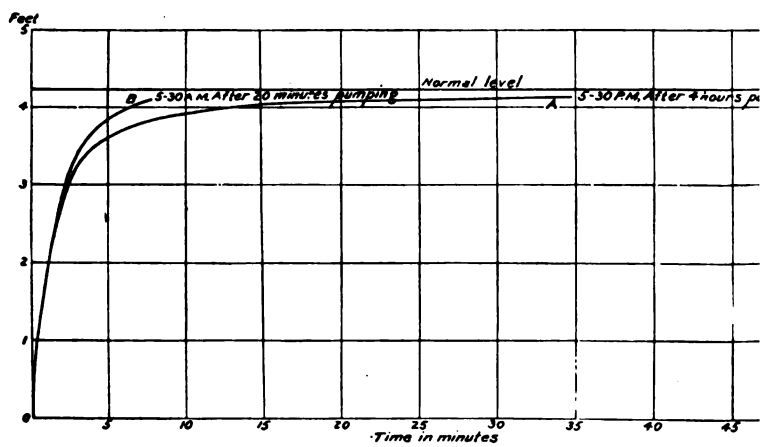


FIG. 21.—Two rising curves for the Root well: Curve A, after four or five hours of pumping; after only twenty minutes of pumping.

Two rising curves of this well were obtained, which make an esting comparison (see fig. 21).

Curve A was taken late in the afternoon, after about four hours' pumping, and curve B was taken after about twenty mi pumping, when the water was lowered to the same depth as the preceding afternoon.

Curve B is much steeper than curve A, showing that the flowed into the well faster. This can be explained by the fa during the short period of pumping (twenty minutes) the cone of ence had not extended as far as in the first case, and there was fore less unsaturated soil to fill with water and a steeper slope ground-water surface.

The specific capacity of the well, determined from these c using the method described heretofore, is 62.5 gallons per m This multiplied by 4.16, the amount of lowering of the well pump, gives 260 gallons per minute, which is 19 per cent abo

served discharge. The percolating surface—area of feeders plus ttom of well—is 210 square feet, and dividing the specific capacity ermined from the discharge by 210 we get 0.246 gallon per minute the specific capacity per square foot of percolating area. This ge error is probably caused by the steep slope given to the rising ve by the leakage of the water from the buckets. The pump must lowered before a greater quantity of water can be recovered, as water at present is lowered to the level of the lower shaft.

This plant has not been utilized for irrigation as yet, but its is contemplated for irrigating about 20 acres of beets, cantaloupes, lons, and garden truck.

The Root plant was installed in the spring of 1904, being completed the latter part of May. Its total cost was as follows.

Cost of Root pumping plant near Larkin, Kans.

	Cost of material.	Labor.		Total cost.
		Time in days.	Cost.[a]	
ll:				
Lumber	$27			$27
Feeders	42			42
Labor—				
Prospecting for location, digging big hole		2	$4	4
Making big curb		9	18	18
Sinking big curb		12	24	24
Sinking feeders		17	34	34
mp	100			100
gine	100			100
Installing			6	6
ed:				
Lumber, nails, and window	33			33
Paint and painting	4			4
Labor			10	10
Total	306		96	402

[a] Labor, $2 a day.

TEST OF WELL AT KING BROTHERS' RANCH, GARDEN, KANS.

This well is located near the west side of sec. 30, R. 33 W., T. 22 S., out 12 miles northwest of Garden, Kans.

The well consists of a shaft, about 5 feet square, sunk 41.4 feet, to ithin 1.2 feet of the water level. From the bottom of this shaft a -inch, perforated, galvanized-iron casing extends down to a depth of .5 feet from the normal surface of the ground water.

It was put down by King Brothers to determine the amount of ound water which could be recovered at this point from a single well d its influence on other wells.

Fifteen feet from the first well a second well was sunk to a depth of 91 feet, 7.9 feet lower than the first well. This second well was put down for the purpose of determining the effect on the water plane of lowering the water in the first well by pumping.

A No. 4 Byron-Jackson centrifugal pump was placed at the bottom of the shaft of the first well and connected by a long belt running over 2 idle wheels to a 14-horsepower thresher engine on the surface of the ground. The discharge was measured by a fully contracted weir with a crest of 1 foot. The head at the time of maximum discharge, when the water in the well was as far down as the pump could lower it, was 0.25 foot, corresponding to a flow of 183 gallons per minute. This maximum rate was very difficult to maintain for any length of time, because of the temporary manner in which the machinery was installed. The belt was liable to slip and allow the water to rise several feet; also the idle wheels at the top of the shaft over which the belt ran were poorly mounted, and at times a stop was necessary to cool off a hot box at that place.

The above discharge was measured when the water level in the well was lowered 20.3 feet by the pump. Dividing the discharge by the distance gives the specific capacity of the well, or the amount of water furnished for 1 foot of lowering, as 9 gallons per minute. The total percolating area of well strainer exposed to the water was 85 square feet. From this it appears that the specific capacity of the well strainer is 0.106 gallon per square foot per minute.

As this was a test of the capacity of the well only, and not of the pumping plant, no indicator cards nor other device was used to get the efficiency of the plant, and no measure was made of the coal burned. The mechanical efficiency would undoubtedly have been low, as there was a constant slipping of the belt, and the idle wheels were home-made, running in wooden bearings, which were smoking constantly.

The maximum lowering of the water in the main well was 20.2 feet, and the corresponding depression of the water plane, 15 feet away, as indicated by the test well, was 3.5 feet. This shows the steep slope of the water plane and the comparatively small radius of the base of the cone of influence.

Readings were taken of the water level in the main well and the test well, and the discharge was noted at intervals. The accompanying curve, fig. 22, shows rising curves for the main well and the test well plotted together. A study of the curve brings out several facts that might well be expected. The rise of the test well lags slightly behind that of the main well. The curve of the main well shows an irregularity due to the caving in of material around the strainer.

King Brothers contemplate sinking 20 of these wells in a north and south line. They propose to connect them all with a tunnel just above the water plane and lay a main suction pipe in this tunnel, with

anches tapping all the wells. The pumps will be located in the shaft eady dug, and connected by a belt to the power plant on the surface. The owners paid 40 cents a foot for sinking the wells and furnished e man. The price paid for the 15-inch, No. 16, iron casing was $1 oot. They contemplate using wooden casing in the remainder of

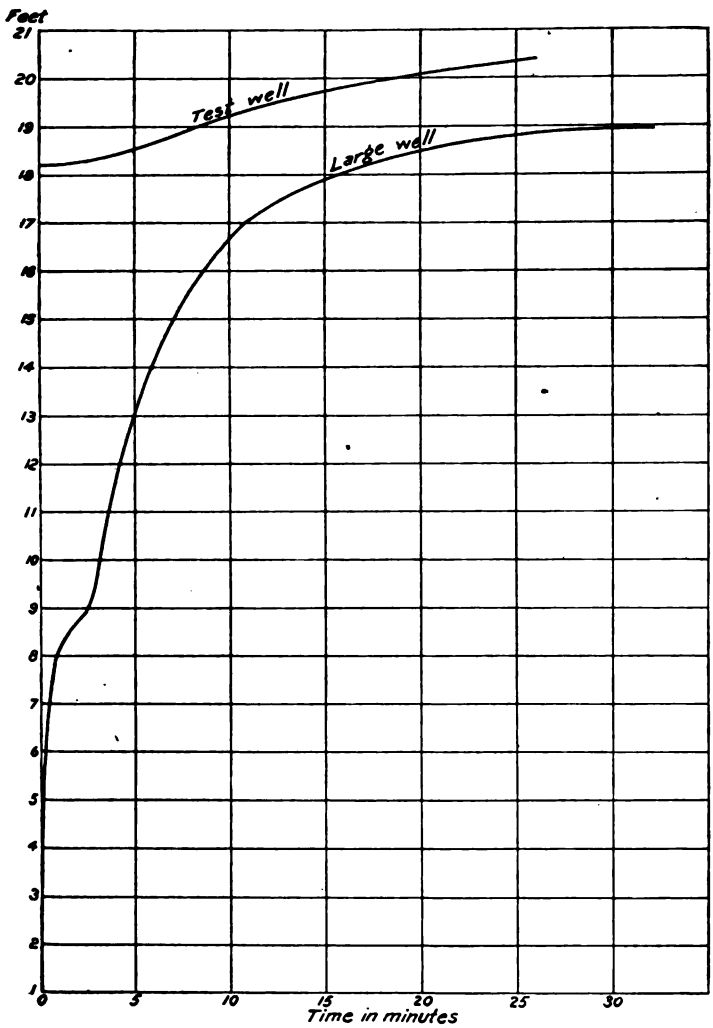


FIG. 22.—Rising curves for main well and test well, King Brothers' plant, Garden, Kans.

he wells. This will be made of pine lumber 1 inch by 3 inches. It rill take 16 such boards to make the circular casing, at a cost of $3.50 er hundred linear feet of lumber. One man, at $1.50, can make and erforate about 25 feet of this casing in a day. This would make the ost of wooden casing 62 cents per foot.

After the tunnels and wells are dug King Brothers purpose to contract for the installation of a compound Corliss engine and centrifugal pump at about $9,500. They expect the plant to raise 4,000 gallons of water per minute, with a 60-foot lift, this being at the rate of 2,000,000 foot-pounds per minute on 4,800 pounds of coal per twenty-four hours. If the coal contain 12,500 British thermal units, and if the boiler efficiency be assumed at 75 per cent, engine 13 per cent, and belt 90 per cent, the pump would be required to have an efficiency of 70 per cent to realize the above expectation. These figures require that the plant turn out 5.9 per cent of the energy in the fuel in the form of useful work.

TEST OF CITY WATERWORKS WELL, GARDEN, KANS.

The first test began at 4.25 a. m. June 28, 1904, when one pump was started. The second pump was started at 5.50 a. m. The hydrants used in flushing the sewers were opened at about 7.30 a. m. and closed at 10.35 a. m. The east pump was stopped at 11.15 a. m.; the west pump was operated constantly all day. On account of the flushing of the sewers an exceptionally large amount of water was pumped during this test.

Gage heights in the well were read every five minutes, and the number of cycles of each pump was recorded every tenth minute for the ten preceding minutes. The pumping machinery consists of two compound steam duplex pumps, with cylinders 8 inches by 12 inches, which are very old and worn. The test was continued until 12.40 p. m. At 8 p. m. the test was again taken up, this being the time when the sprinkling of lawns is stopped. The cycles of the engine were counted and well heights taken as before.

Pumping is stopped at 9 p. m. Sprinkling of lawns is allowed from 7 to 11 a. m. and from 4 to 8 p. m. Most of the rise of water in the well occurs before 9 p. m., when the pump is stopped. A plug was made for the feeder and inserted July 7, but it did not fit tight enough to stop the flow. The rising curve was taken July 7 in the evening and also July 8, when the plug was driven down so as to be water-tight. July 11 the rising curve was again taken when the water was lower.

The well is 16.2 feet inside diameter and 20 feet deep. The bottom is about 8.9 feet below the normal level of the ground water. There is a 10-inch feeder in the bottom of the well, which extends to a depth of 42 feet below the ground and about 3 feet above the bottom of the large well. It is open at the bottom and perforated 10 inches up from the bottom. The water level is about 11 feet below the ground level.

Data of city waterworks well, Garden, Kans.

	Feet.
of top of well roof	2,837.26
:o top of gage	10.35
top to 0	13.25
	23.60
, water normal	8.72
levation of water	2,822.38
:vel	2,832.00

on of bottom of well 2,813.66=0 of gage.

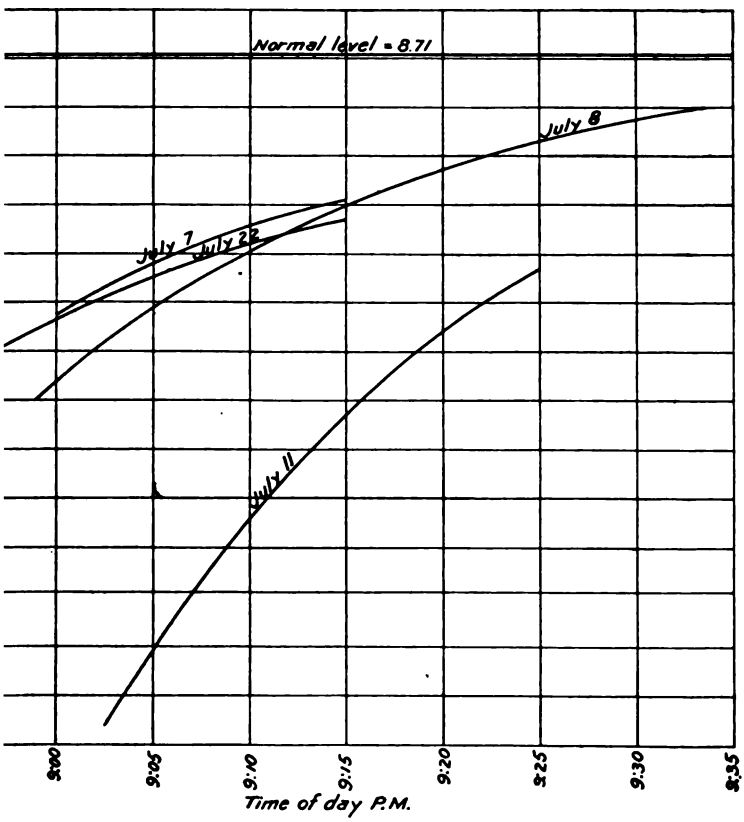


FIG. 23.—Rising curves for city waterworks well, Garden, Kans.

ising curves obtained for this well on June 28, July 7, 8, and eproduced in fig. 23. Fig. 24 gives the engine cycles and ele- of water in the well for several hours of heavy pumping on 3, 1904, while the sewers were being flushed. The displace- the two cylinders of one of the pumps amounts to 1.362 cubic The curve in fig. 24 enumerates the cycles of pumps, so that l discharge of the pumps can be obtained, if no allowance be

made for slip, by multiplying the number of cycles by 1.362. The discharge, computed in this way, amounts to 685 gallons a minute.

The amount of slip is enormous. Using the rising curve for June 28, we may place H=0.65, h=0.46, and A=204.5 square feet in the formula for specific capacity. This gives a specific capacity

$$c=53 \text{ gallons a minute.}$$

This result is much below the normal on account of the excessive amount of pumping on that day, due to the flushing of sewers. The maximum amount of lowering of the water in the well was 5.48 feet,

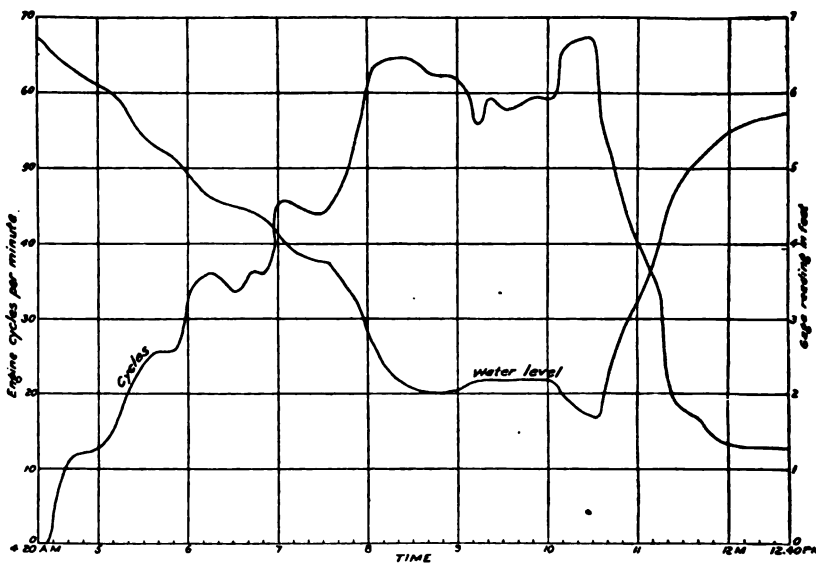


FIG. 24.—Elevation of water in city well, Garden, Kans., and engine cycles of steam pump during heavy pumping while flushing sewers, June 28, 1904.

which occurred at 10.30 a. m., when the pump cycles numbered 67 per minute. Multiplying 5.48 by 53, the total discharge at that time is found to be 290 gallons a minute. The slip of the pump must therefore have amounted to 57 per cent at this time.

Using the rising curve of July 7, the specific capacity of the well is found to be 67 gallons a minute. The following table shows the specific capacities computed for the several dates:

Specific capacity of city waterworks well, Garden, Kans., 1904.

Rising curve.	Specific capacity per minute.
	Gallons.
June 28, 8.55 to 9.05 p. m	5
July 7, 9 to 9.10 p. m	6
July 8, 9 to 9.10 p. m	7
July 11, 9.05 to 9.15 p. m	9

These results furnish interesting comparisons. The low specific apacity on June 28 was obtained after the prolonged and excessive ›umping for flushing of the sewers. There was a light rain on the ıight of July 6, and a heavy rain on the night of July 7, which influ- ›nced both the consumption of water in the city, and in a slight degree .he amount of ground water available.

On July 8 and 11 the feeder in the bottom of the well was plugged. The plug did not leak, but the casing of the feeder must have leaked badly since no influence upon the specific capacity of the well can be detected.

In Water-Supply Paper No. 67,[a] a rising curve for this same well is given, as observed by Johnson in 1900. From that curve it is possible to compute the specific capacity of the well in 1900. The following determinations are based upon various intervals after pumping has stopped, as indicated in the table. The specific capacity of a well always appears to be lower than its true value, if the very last portion of the rising curve be used, since at this period a large fraction of the water is being utilized in filling up the ground around the well.

Specific capacity of city waterworks well, Garden, Kans., 1900.

Intervals.	Specific capacity per minute.
	Gallons.
0-10 minutes	73.0
0-20 minutes	71.0
0-30 minutes	66.4
0-50 minutes	63.0
20-40 minutes	59.0
40-50 minutes	55.0

These results seem to be identical with those obtained in 1904.

The average specific capacity (77 gallons a minute) as determined in 1904 indicates that the maximum yield of the well, if the water in the well be lowered 8 feet, is 615 gallons a minute. The pumps in use at present can not pump much more than half of this amount of water on account of the worn condition of pistons and cylinders.

The total percolating surface of the well bottom and strainer of the feeder is 247 square feet. From this it can be deduced that the specific capacity of the well is 0.31 gallon a minute per square foot of percolating surface.

[a] Slichter, C. S., The motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, p. 68.

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TEST OF HOLCOMB'S PUMPING PLANT.

A very important attempt to recover water from the underflow was begun in the 1904 season by the owners of the Riverside stock ranch, about 7 miles west of Garden, Kans. A well 200 feet long and 5 feet wide, excavated to a depth of 9 to 10 feet below the water plane was constructed of sheet piling, and 11 galvanized-iron feeders were inserted in the bottom of the wells to a depth of about 20 feet. A 75-horsepower Corliss engine with condenser, a 90-horsepower boiler, and a No. 15 Byron-Jackson centrifugal pump were put in position at the north end of the well. Foundations for the engine and pump and buildings to cover the machinery were constructed in a very substantial manner. As soon as the engine and pump are in satisfactory working order it is purposed to sink a large number of additional feeders in the bottom of the well in the expectation of increasing its capacity to 6,000 gallons per minute. The approximate cost of the plant is about $8,000 for machinery and $4,000 for the well. Trinidad slack coal is used for fuel at a cost of $4 to $4.50 per ton.

The construction of this pumping plant has attracted very wide attention and if it proves to be a success it will mean a great deal for the progress of irrigation in the bottom lands of Arkansas Valley. There is some question whether 6,000 gallons per minute can be obtained from the present well, even with a very large number of additional feeders, but it will be entirely practicable to increase the length of the well without very much additional expense. The present well, with ten 20-foot feeders, 16 inches in diameter, would furnish about 6,000 gallons per minute, if we can rely upon a specific capacity of one-third gallon per minute for each square foot of strainer. This would require, however, the lowering of the natural level of the water to a distance of 10 feet, which is somewhat more than would be best for the most economical running of the plant.[a]

Both suction and discharge pipe of the centrifugal pump are made of No. 16 galvanized iron, riveted and soldered. A 20-inch flap valve is placed at the upper end of the discharge pipe, dispensing with the use of a foot valve. The pump is primed before starting by opening a 1-inch valve in a lead pipe from the main pump to the air pump. When the proper vacuum is shown by the gage the 1-inch valve is closed and the engine started.

A test run of the plant was made for five days, from July 18 to 23, 1905. The engine was started at the lowest speed at which it would work the pump satisfactorily. After running at this rate for forty-eight hours the speed was increased until nearly the full capacity of the well had been reached.

The amount of water pumped during the test averaged about 2,300 gallons a minute, or 5 cubic feet of water a second. This is equivalent

[a] Actual test of the plant shows that this amount of water can not be recovered without extending the well

› a daily discharge of 10 acre-feet, or a sufficient amount of water to over 10 acres of land 1 foot deep. As is well known, the present well ; not sufficiently large to supply the pump and engine with all of the vater that they are designed to handle; in fact, the pump and engine re capable of handling three times the amount of water at present vailable for long-continued runs. It is expected that by clearing out he feeders at present in the well, and by enlarging the well, the apacity of the plant will be greatly increased; but even at the present ow rate of delivery, and consequent rather low efficiency of the nachinery, the cost of water delivered is comparatively low.

The average amount of coal consumed was 2,450 pounds per twenty-four hours, or about 1¼ tons per day. At $4 a ton the daily cost of coal was $5 per twenty-four hours. The cost of labor for the day and night man, each at $1.25 per day, makes the cost for coal and labor $7.50 per twenty-four hours. The cost of lubricating oil and miscellaneous supplies may be estimated at $1 a day, making a total cost of $8.50 per twenty-four hours. At this rate the cost of water was 85 cents per acre-foot, not including interest on the plant nor any allowance for depreciation and repairs on the machinery and well. If these latter items be included, the cost of water would be very materially increased.

It seems, however, unfair to estimate these charges at the present time, as the expense of erecting the plant was incurred on the basis of securing a very considerably larger amount of water than is at present delivered; for that reason the interest charges would be very high, if charged against the present amount. It seems very probable that if the supply of water from the well is sufficiently increased the plant will ultimately be capable of delivering water into the ditch at a cost not to exceed $1 per acre-foot, including a moderate charge for interest and depreciation on machinery, but not including any profit.

The following tables show the fuel consumed and the data obtained during the test. The well was not of sufficient size to supply the pump with water, and toward the end of the run difficulty was experienced in operating the plant. Occasionally the water became so low that air would be taken into the suction pipe, and the plant would have to be stopped to prime the pump. In order to secure proper returns, it will be necessary to enlarge the well to about three times its present capacity, otherwise the engine and pump will be entirely 'oo large for the well.

Consumption of coal at test of Holcomb pumping plant.

	Pounds.
July 20, 6 a. m. to 6.30 p. m	1,386
July 20, 6.30 p. m. to July 21, 6.20 a. m	1,386
July 21, 6.20 a. m. to 6 p. m	1,134
July 21, 6 p. m. to July 22, 6 a. m.[a]	1,260
July 22, 6 a. m. to 6.30 p. m	1,134
July 22, 6.30 p. m. to July 23, 6.30 a. m.[b]	1,134
July 23, 6.30 a. m. to 2.40 p. m	832
	8,266

Data of test of Holcomb pumping plant.

[From 7.54 a. m., July 18, to 2.40 p. m., July 23.]

Date.	Hour.	Discharge of flume.		Depth of water below its initial position.	Speed in revolutions per minute.	
		Cubic feet per second.	Gallons per minute.		Engine.	Pump.
				Feet.		
July 18..	7.54 a. m	0	0	0	0	0
July 18..	8 a. m	13.33	5,980	4.40	75	350
July 18..	8.45 a. m	7.42	3,330	7.25	73	344
July 18..	9.30 a. m	7.38	3,310	7.27	73	345
July 18..	11.20 a. m	6.29	2,820	7.44	73	344
July 18..	2.25 p. m	5.87	2,630	7.61	73	350
July 18..	4.25 p. m	5.32	2,380	7.61	73	344
July 18..	5 p. m	4.89	2,190	7.62	73	344
July 19..	7.15 a. m	4.67	2,090	7.80	73	344
July 19..	9.30 a. m	4.72	2,110	7.74	72	344
July 20..	7 a. m	5.30	2,380	7.87	74	346
July 20..	7.45 a. m	4.67	2,090	8.40	75	352
July 21..	6 a. m	5.82	2,610	8.50	74	345
July 21..	8 a. m	5.68	2,540	9.50	77	350
July 21..	8.20 a. m	5.30	2,380	9.53	77	350
July 22..	7 a. m	5.03	2,250	9.30	76	357
July 23..	.....do	5.15	2,310	9.60	77	351

TEST OF PRODUCER-GAS PUMPING PLANT NEAR ROCKY FORD, COLO.

The future of irrigation in the bottom lands of Arkansas Valley will be greatly influenced by the cost of power for pumping water. One of the possible ways of cutting down this cost is by the use of producer-gas in gas engines, as mentioned in Chapter V.

A 35-horsepower producer-gas plant has been installed by Mr. A. W. Shelton, about 6 miles northeast of Rocky Ford, Colo. It consists of a 40-horsepower Pintsch suction gas producer, a 35-horsepower single-cylinder gas engine, and a 12-inch Byron-Jackson vertical-shaft centrifugal pump. The water is pumped from a canal through 15-inch concrete tile (200 feet of intake and 300 feet of discharge) to an eleva-

[a] Stopped 35 minutes. [b] Stopped 36 minutes.

tion of 16 feet above the level of the water in the canal, called the first discharge, and at another point to an elevation of 28 feet above the level of the water in the canal, called the second discharge.

A test was made of this plant, extending from December 2 to 6, 1905. The results of the test of the engine and producer-gas apparatus are given herewith. Unfortunately the cement-discharge pipe gave out when the plant was first started, so that water could not be pumped during the test, and the hydraulic data for this plant are therefore not available.

In connection with the generation of the gas a vaporizer, scrubber, and purifier are used. Water is evaporated at atmospheric pressure to generate the steam required in the producer. The vaporizer is located directly on top of the producer. The scrubber is of the form in which a spray of water trickles down through coke, the water running out at the bottom of the scrubber. After being scrubbed the gas passes through a purifier box, next through a gas governor, and then to the engine.

The engine used was one of the Olds gasoline type, somewhat modified for the use of producer-gas. The engine governor was not the one belonging to the engine.

A belt was connected from a 30-inch pulley on the engine to a pulley on the vertical shaft of the centrifugal pump. A clutch at the engine shaft allowed the pump to be disconnected at will.

A small pulley, fastened to the shaft opposite the pulley end, carried a belt which drove a 3 by 5 inch "Baker" feed-water pump. This pump, making about 45 revolutions a minute, drew water from the well and discharged it into a 3 by 8 feet by 30 inches storage tank near the roof of the building and above the producer. A pipe leading from the bottom of this tank furnished all the water used to operate the plant, viz, water for the engine jacket, steam, and scrubber. During the brake tests it also supplied cooling water for the brake. The water, after being used, passed through the seals and then into the well from which it was drawn.

Preliminary brake tests of gas engine at pumping plant of A. W. Shelton, near Rocky Ford, Colo., December 4, 1905.

Test.	Net load, in pounds	Speed, in revolutions per minute.	Explosions per minute.	Mean effective pressure, in pounds per square inch.	Brake horsepower.	Indicated horsepower.	Mechanical efficiency (per cent).	Maximum pressure of explosion, in pounds per square inch.	Maximum pressure of compression, in pounds per square inch.
1	151	199	99.5	44.0	26.7	34.0	78.5	225	140
2	169	200	100.0	45.6	30.0	35.4	84.9	235	133
3	174	199	99.5	50.0	30.7	38.7	79.4	235	148

Diameter of piston ..... 14 inches
Length of stroke ..... 20 inches
Length of brake arm ..... 56 inches

Brake constant $=\frac{2\times\pi\times56}{12\times33000}=$ ..... .00088

Engine constant $=\frac{20\times\pi\times14\times14}{12\times4\times33000}=$ ..... .00778

Brake horsepower = ... Net load × Speed × .00088
Indicated horsepower = ... Mean effective pressure × Explosions × .00778

Mechanical efficiency $=\frac{\text{Brake horsepower}}{\text{Indicated horsepower}}$.

Indicator spring, pounds per square inch, = 160 for Test No. 1, 250 for Test No. 2, and 250 for Test No. 3.

Of the gas producer a test of three hours' duration was made. The gas governor was not in operation. The producer was filled with coal at the beginning, as well as at the end of the run. As the engine was not operating well the load had to be taken off for a time.

Test of gas producer at pumping plant of A. W. Shelton, near Rocky Ford, Colo., December 4, 1905.

Time.	Net brake load.	Revolutions per minute.	Explosions per minute.	Temperature °F.					Coal.
				Jacket water.			Engine room.	Outside air.	
				Entering.	Leaving.	Range.			
P. m.	*Pounds.*								*Pounds.*
1.35	181	204	102	45	154	109	60	50	.....
1.50	181	208	104	45	160	115	60	50	.....
2.05	181	.....	.....	.....	166	.....	60	49	.....
2.20	181	206	103	45	165	120	64	48	.....
2.35	181	206	103	45	165	120	64	48	21
2.50	181	206	103	45	208	163	64	47	24
3.05	Load partly off.	204	102	45	208	163	.....	46	.....
3.20		202	101	45	.....	.....	.....	46	.....
3.35		.....	.....	.....	.....	.....	.....	45	.....
3.50		.....	.....	.....	.....	.....	.....	44	17
4.05	181	213	117	45	.....	.....	.....	43	18
4.20	181	220	110	45	.....	.....	.....	42	.....
4.35	181	.....	.....	45	.....	.....	.....	41	21
Av.....	125	207	105	45	175	132	62	46	.....
Total ..	.....	.....	.....	.....	.....	.....	.....	.....	104

Summary of test of gas producer at pumping plant of A. W. Shelton, near Rocky Ford, Colo., December 4, 1905.

Duration of test ..... 3 hours.
Net brake load (maximum) ..... 181 pounds.
Net brake load (average) ..... 125 pounds.
Revolutions per minute (average) ..... 207.
Explosions per minute (average) ..... 105.
Temperature of water entering jacket (average) ..... 45° F.
Temperature of water leaving jacket (average) ..... 175° F.
Range of jacket-water temperature ..... 132° F.

Temperature of engine room (average) ..... 62° F.
Temperature of outside air (average) ..... 46° F.
Total coal consumed ..... 104 pounds.
Pressure maximum explosion ..... 258 pounds per square inch.
Pressure maximum compression ..... 145 pounds per square inch.
Pressure, suction at exit of producer ..... 2 inches water.
Pressure, suction at exit of scrubber ..... 2.125 inches water.
Pressure, suction at exit of purifier ..... 2.25 inches water.
Pressure, mean effective ..... 51.6 pounds per square inch.
Indicated horsepower $(51.6 \times 105 \times .00778) =$ ..... 42.2.
Brake horsepower (maximum) $= (181 \times 207 \times .000888) =$ ... 33.2.
Brake horsepower (average) $= (125 \times 207 \times .000888) =$ ..... 22.9.
Mechanical efficiency (maximum) $\frac{33.2}{42.2}$ ..... 78.9 per cent.
Mechanical efficiency (average) $\frac{22.9}{42.2}$ ..... 54.2 per cent.
Pounds of coal per brake horsepower per hour, based on maximum brake horsepower $\left(\frac{104}{3 \times 33.2}\right)$ ..... 1.05.
Pounds of coal per brake horsepower per hour, based on average brake horsepower $\left(\frac{104}{3 \times 22.9}\right)$ ..... 1.51.

Test of gas engine at pumping plant of A. W. Shelton, near Rocky Ford, Colo., as shown by sample indicator card.

Duration of test (10 a. m. to 5 p. m.) ..... 7 hours.
Rated horsepower of engine ..... 35.
Weight of engine ..... 11,000 pounds.
Mean effective pressure (average of 54 cards)[a] ..... 43.7 pounds per square inch.
Indicator spring ..... 160 pounds per square inch.
Load on brake ..... 175 pounds.
Revolutions per minute ..... 201.6.
Explosions per minute ..... 100.8.
Brake horsepower $(175 \times 201.6 \times .000888)$ ..... 31.4.
Indicated horsepower $(43.7 \times 100.8 \times .00778)$ ..... 34.3.
Mechanical efficiency $\left(\frac{31.4}{34.3}\right)$[a] ..... 91.5 per cent.
Kind of producer ..... Pintsch.
Producer rated horsepower ..... 40.
Temperature of water entering jacket ..... 49.8° F.
Temperature of water leaving jacket ..... 165.8° F.
Range of jacket-water temperature ..... 116° F.
Temperature of outside air ..... 46.8° F.
Temperature of engine room ..... 72.0° F.
Pressure of maximum explosion ..... 260 pounds per square inch.
Pressure of maximum compression ..... 150 pounds per square inch.
Pressure of maximum steam ..... Atmospheric.
Pressure of maximum suction at producer exit ..... 2.2 inches water.
Pressure of maximum suction at scrubber exit ..... 2.2 inches water.
Pressure of maximum suction at purifier exit ..... 2.4 inches water.

[a] The high mechanical efficiency is probably due to an error in the indicated horsepower. The mean effective pressure appears to be too low. The reducing motion used was made of wood and had become considerably worn when this test was made.

Data concerning coal used in test of producer-gas pumping plant of A. W. Shelton, near Rocky Ford, Colo.

Kind	Colorado anthracite, Floresta mine.
Cost at plant per ton	$6.
Size	Pea.
Total quantity fired	325 pounds.
Total refuse (clinkers, ash, and unburned coal)	66 pounds.
Total clinkers	5 pounds.
Total unburned coal	43 pounds.
Total ash (siftings)	18 pounds.
Calorific value of coal per pound	13,850 B. T. U.
Pounds of coal per brake horsepower per hour, as fired and uncorrected for unburned coal in refuse $\left(\frac{325}{7\times31.4}\right)$	1.48.
Pounds of coal per brake horsepower per hour (corrected for unburned coal in refuse)	1.24.

Approximate analysis of coal used at producer-gas pumping plant of A. W. Shelton, near Rocky Ford, Colo.

	Per cent.
Moisture	2.2
Volatile matter	7.6
Fixed carbon	83.8
Ash	6.4

Water used per hour in producer-gas pumping plant of A. W. Shelton, near Rocky Ford, Colo.

	Pounds.
By jacket	1,200
By brake	930
By scrubber (approximately)	1,300
By vaporizer	16

Efficiencies at various loads of producer gas pumping plant of A. W. Shelton, near Rocky Ford, Colo.; test of December 6, 1905.

Time.	Net brake load (lbs.).	Revolutions per minute.	Explosions per minute.	Jacket water.				Mean effective pressure (pounds per square inch).	Indicated horsepower.	Brake horsepower.	Mechanical efficiency (per cent).
				Temperatures.			Pounds per hour.				
				Inlet.	Outlet.	Range.					
9.50	27	205	45.0	44	104	60	1,260	44.1	15.4	4.9	30.0
10.13	50	203	52.2	44	107	63	1,570	41.1	17.9	9.0	50.2
10.42	75	203	59.4	42	112	70	1,300	44.9	20.7	13.5	65.2
11.06	100	203	69.3	42	117	75	1,340	44.1	23.8	18.0	75.6
11.30	125	203	83.0	42	126	84	1,340	43.7	28.2	22.5	79.8
12.25	150	199	96.0	42	136	94	1,570	42.4	31.6	26.5	83.8
1.18	175	201	100.5	42	145	103	1,570	39.9	31.2	31.2	.....
1.40	200	189	95.0	42	140	98	1,570	39.9	29.5	33.6	.....
2.00	215	178	89.0	42	148	106	.....	41.3	28.6	33.9	.....
.....	[a] 225	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[a] Engine would not carry load.

s of gas from gas producer at pumping plant of A. W. Shelton, near Rocky Ford, Colo.

	Per cent.	B. T. U. per 100 cubic feet of gas at 60° F.
CO_2	6.3	.....
O	1.0	.....
CO	23.2	7,513
CH_4	0.0	.....
H	18.6	6,107
N	50.9	.....
	100	13,620

will be observed from the results obtained in the test that 1.24 ds of coal per hour produced 1 brake horsepower. At $6 a ton ost of fuel was therefore three-eighths of a cent per brake-horse- r hour. At this rate power was obtained at a cost for fuel alent to gasoline at 3 cents per gallon. One-half cent per brake- power hour for labor and five-eighths cent per brake-horse- r hour for supplies, depreciation, and repairs should cover all charges. The total cost of power should not exceed, there- 1½ cents per brake-horsepower hour, or about $4.50 per day of ours, for the present plant. In this length of time the plant d furnish about 8 acre-feet of water on the 16-foot lift, or at a f about 58 cents per acre-foot.

e first cost of the pumping plant in round numbers, was $3,300 e producer, engine, and pump; $200 for the building, and $1,500 e intake and discharge pipe and flumes.

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MAY, 1906.

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Water-Supply and Irrigation Paper No. 154

Series { B, Descriptive Geology, 81
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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE GEOLOGY AND WATER RESOURCES OF THE ASTERN PORTION OF THE PANHANDLE OF TEXAS

BY

CHARLES N. GOULD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1906

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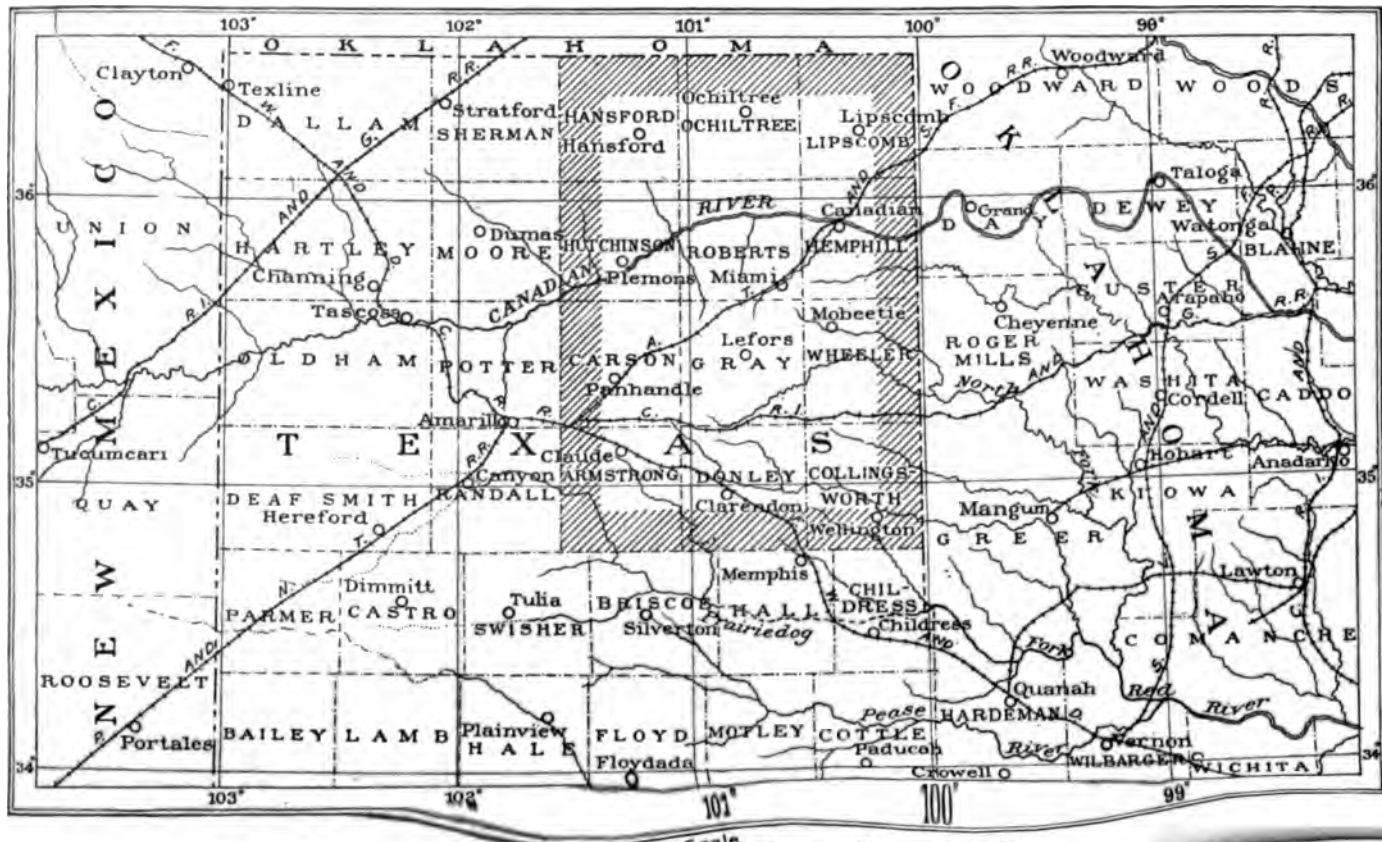

103°
102°
101°
100°
99°
36°
35°
34°
O K L A H O M A
Clayton
Texline
Stratford
SHERMAN
HANSFORD
Hansford
Ochiltree
OCHILTREE
Lipscomb
LIPSCOMB
Woodward
WOODWARD
WOODS
Taloga
DEWEY
Watonga
BLAINE
UNION
HARTLEY
Channing
Dumas
MOORE
HUTCHINSON
Plemons
ROBERTS
Miami
Canadian
HEMPHILL
RIVER
CANADIAN
Tascosa
Mobeetie
Lefors
GRAY
WHEELER
Cheyenne
ROGER MILLS
CUSTER
Arapaho
OLDHAM
POTTER
CARSON
Panhandle
Amarillo
WASHITA
Cordell
CADDO
Tucumcari
T E X A S
Claude
Canyon
ARMSTRONG
DONLEY
COLLINGS-WORTH
Hobart
Anadarko
QUAY
DEAF SMITH
Hereford
RANDALL
Clarendon
Wellington
Mangum
KIOWA
GREER
Memphis
Lawton
Dimmitt
PARMER
CASTRO
Tulia
SWISHER
BRISCOE
Silverton
HALL
Prairiedog
CHIL-DRESS
Childress
COMANCHE
ROOSEVELT
Quanah
Pease
HARDEMAN
Red
River
Portales
BAILEY
LAMB
Plainview
HALE
FLOYD
Floydada
MOTLEY
COTTLE
Paduca
Vernon
WILBARGER
Crowell
WICHITA
Scale 50 75 100 miles

GEOLOGY AND WATER RESOURCES OF THE EASTERN PORTION OF THE PANHANDLE OF TEXAS.

By Charles N. Gould.

INTRODUCTION.

Area covered.—The area described in this report lies in the northeastern part of the Texas Panhandle, and includes the following 12 counties: Lipscomb, Ochiltree, Hansford, Hutchinson, Roberts, Hemphill, Wheeler, Gray, Carson, Armstrong, Donley, and Collingsworth, each of which is approximately 30 miles square. It is an area 90 miles east and west and 120 miles north and south, situated south of the center of the Great Plains. The total area is approximately 10,800 square miles. It extends from 100° to 101° 35′ west longitude and from 34° 45′ to 36° 30′ north latitude. On the north and east it is adjoined by Oklahoma.

Sources of data.—The field work upon which this report is based was done during the years 1903 and 1904. During the former season little more was accomplished than a general reconnaissance in the region adjacent to Canadian River, through Carson, Hutchinson, Roberts, and Hemphill counties to the Oklahoma line, thence south through Hemphill, Wheeler, and Collingsworth counties as far as Elm Fork of Red River. On this trip the writer was assisted by Messrs. Charles T. Kirk, Chester A. Reeds, Charles A. Long, and Pierce Larkin, students in the University of Oklahoma. During the field season of 1904 the writer made an examination of the area to which this report relates, assisted by Prof. E. G. Woodruff. Most of the counties were studied in detail, excepting on the broader plains areas, of which only a reconnaissance was made. The well records were mostly secured from farmers and ranchmen by correspondence. Professor Woodruff has assisted in the preparation of the manuscript, "Topography" and "Water conditions by counties" being principally his work.

TOPOGRAPHY.

GENERAL FEATURES.

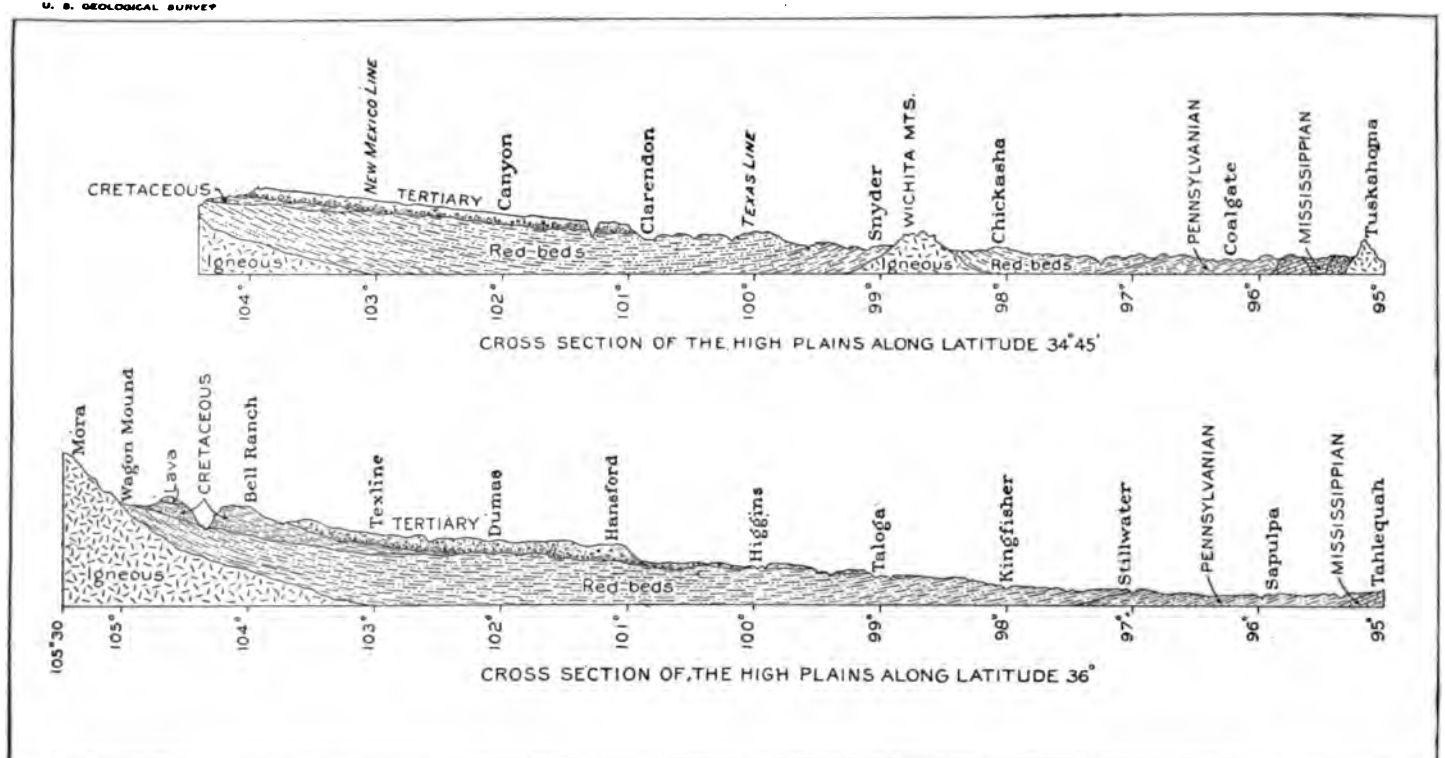
The region here described lies in the southern part of the Great Plains. Its general slope is to the east, with only a slight gradient to the south. The topography is properly divisible into two classes—the High Plains and the eroded plains—with local modifications produced by dune sands. A third and more local phase is found in the river flood plains. The location is shown on Pl. I, and the general features are indicated in the two general cross sections of the Great Plains shown on Pl. II, and on Pl. III, which includes the general region of the High Plains.

HIGH PLAINS.

Surface features.—The region here treated as the High Plains includes not only the northern portion of the Llano Estacado or Staked Plains of Texas and New Mexico, but also the high, level plains in the region north of Canadian River. It seems probable that this area was once a great plain extending far to the east, with moderate slope covered by the deposits of the meandering rivers which were flowing from the mountains and depositing their load of sediment. By this deposition of material the stream beds were filled and the water forced to a new channel. By continued shifting of streams, irregular layers were deposited with much less uniform bedding than those of marine deposition. It is thought that the material composing the High Plains was laid down in this way upon the red beds, the basal formation in this region.

In later times the High Plains have been extensively cut into by stream erosion, until at present, in the region under discussion, the original level surface remains only in those localities more remote from the larger valleys. From a geological standpoint the erosion of the High Plains has been rapid and is still vigorously in progress. In the region comprised in this report High Plains constitute portions of the following counties: Western Lipscomb, most of Ochiltree and Hansford, southwestern Hemphill, southern Roberts, northwestern Hutchinson, western Gray, nearly all of Carson, and portions of Donley and Armstrong, including the greater part of the region mapped as Tertiary on Pl. V, an area of approximately 4,000 square miles.

In general the surface of the High Plains is so nearly level that railroads require little or no grading, and wagon roads go directly from point to point. With a surface so nearly level drainage is wholly undeveloped. Rain water can not run off, but either evaporates or collects in broad, shallow depressions, known in some locali-



GEOLOGIC SECTIONS ACROSS A PORTION OF NORTHWESTERN TEXAS.

ties as playa lakes, from which it escapes by evaporation or seepage. The evaporation is very great, but since the showers are generally vigorous, much of the water finds its way into these flat basins. For this reason the agencies which in most regions are carving valleys and hills are here having little effect upon the plains, and the interior surface level remains intact.

Valleys and canyons.—There are, however, upon the surface of the plain a number of streams which have their sources far in from the escarpment, and there are all gradations of topographic form from the almost featureless surface of the High Plains down through valleys and canyons to the general escarpment facing the lower eroded plains.

In the northern part of the Panhandle the High Plains are being rapidly dissected by a number of small streams, of which Coldwater, Palo Duro, and Wolf Creeks, tributaries of North Fork of Canadian River, are the most important. Besides these, the main Canadian, which rises in the mountains of New Mexico and flows east across the plains, traverses this region in a great valley that is from 5 to 20 miles wide and 600 feet deep. Numerous small streams tributary to Canadian River are now cutting back into the plains and giving the edge, when viewed as a whole, a ragged appearance.

To the south several tributaries of Red River, particularly North Fork, Elm Fork, Salt Fork, Spillers Creek, and Mulberry Creek, have their headwaters in the steep slope of the escarpment, and on account of the relatively low level of the main stream are able to erode more quickly. The level surface of the High Plains is generally retained, but the edges are being rapidly eroded by the streams which find their source either in the escarpment or on the plains.

Escarpment.—From the High Plains to the eroded plains there is in most places an abrupt descent. The escarpment is usually steep, in places being a distinct cliff, 200 to 500 feet high above the eroded plains, but ordinarily the descent is more gradual, occupying a distance of 5 or 6 miles. It is usually a distinct topographic unit, varying in width from 1 mile along Palo Duro Canyon to 6 miles or more in Lipscomb County. Along the larger streams, particularly the Canadian and the branches of Red River, the escarpment is usually sharp and steep, while along the smaller streams it has a gradual slope.

The escarpment (Pl. X, A), which is known locally as "the breaks," marks the limit of the High Plains. It margins the valleys and passes in a broad curve from one drainage system to another. The region abounds in bad-land erosion forms, short ridges, steep talus slopes, isolated conical hills, buttresses, peaks, and numerous narrow, V-shaped valleys, which on becoming larger develop into impassable canyons. The breaks, particularly along the steep slopes,

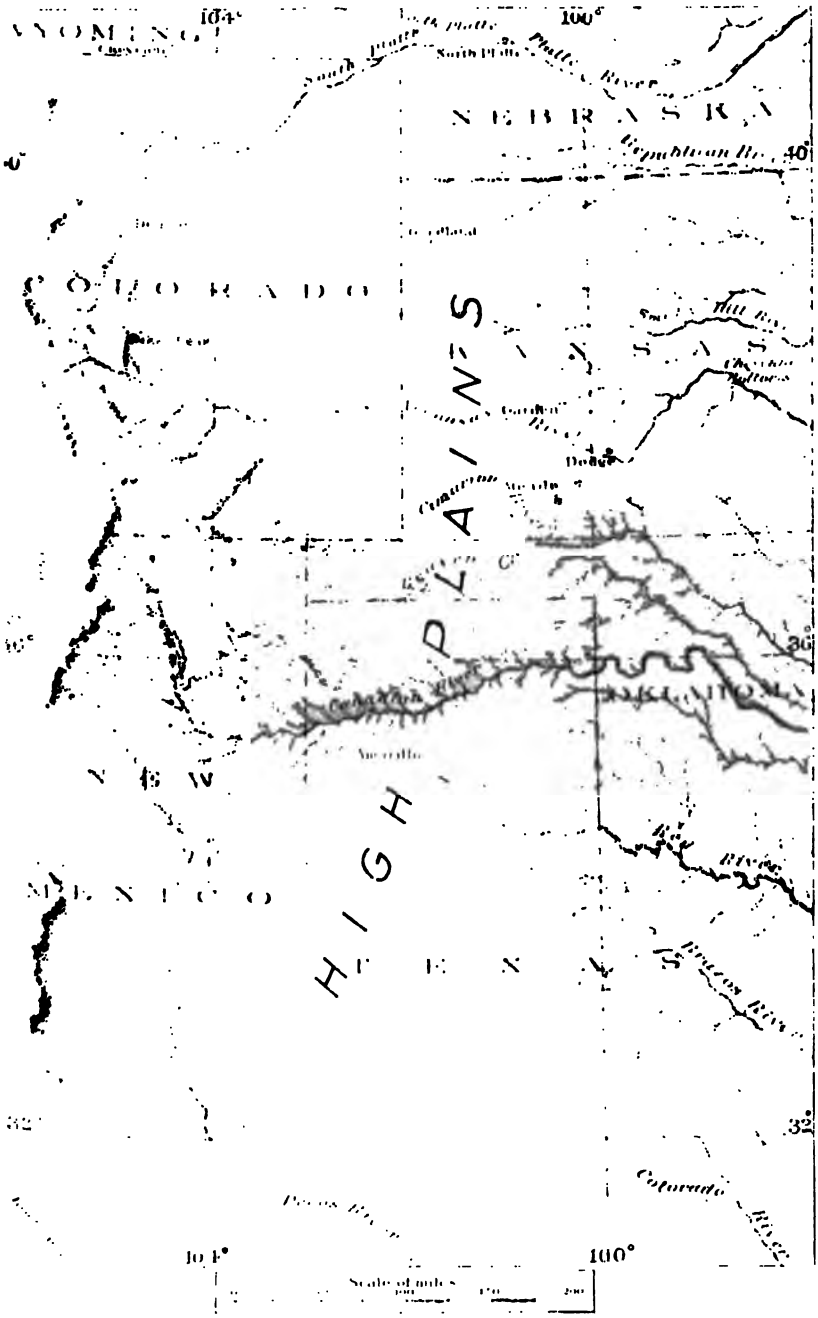
have a sparse vegetation, since the very rapid erosion prevents most kinds of plants from obtaining a foothold. Bunch grass, yucca, and dwarf mesquite are often present. Such a region is most difficult to traverse, and in localities where the breaks are conspicuous it can be crossed with a wagon only at infrequent intervals over specially selected routes. This escarpment is most typical along the Canadian and in Palo Duro Canyon, in Armstrong County.

ERODED PLAINS.

Interstream highlands.—From the High Plains the escarpment forms a descent to the lower level of the eroded plains, which occupy the entire eastern part of the region to which this report relates. From the eroded plains the Tertiary and Pleistocene rocks, which compose the High Plains, have been entirely removed, and the streams, both large and small, are now cutting deep valleys into the subjacent red beds. This part of the Panhandle is a rolling plain, which is now being eroded rapidly, yet without the conspicuous bad-land forms that mark the escarpment. The streams are confined almost entirely to rather deep, steep-sided valleys; the plains between are rolling and well drained.

Standing on this plain not far from the escarpment are outlying hills, generally conical, but often elongated, and joined into irregular ridges. They sometimes attain a height of 100 to 200 feet. These hills have resulted from the thickening and hardening of certain of the upper members of the red beds, usually ledges of sandstone, gypsum, or dolomite, which resisted erosion and protected the relatively softer clays and shales beneath. A line of such hills extends from near Shamrock, in Wheeler County, southwest to beyond Memphis, the county seat of Hall County. South from Shamrock the ridge reaches its maximum width near the post-office of Dozier, at which place the range is 10 miles wide. Here it consists of a number of isolated mesa-like hills rising 100 feet above the eroded plains and capped by a ledge of sandstone, described under "Geology," 6 to 1[illegible] feet thick. The most typical of these hills are Rocking Chair Mountain, north of Elm Fork; Antelope Hills, northeast of Dozier; the Dozier Mounds, southeast of Dozier, and Flat Top, northwest of Dozier. The range is interrupted in northern Collingsworth County by Salt Fork of Red River, but again becomes conspicuous in the southwestern portion of the county, where the creeks are rapidly trenching the valleys between the mesas and bringing the hills into strong relief.

Valleys and canyons.—Crossing the eroded plains at intervals are a number of streams which have their rise on the High Plains, and, after cutting through the escarpment, find their way into the larger



THE HIGH PLAINS

rivers which receive the drainage of the Panhandle. For the most part these streams have carved valleys averaging 3 miles wide and 100 to 200 feet deep in the eroded plains. These streams have already been mentioned, and they will be discussed in more or less detail under "River plains."

SAND HILLS.

The sand hills form an important topographical feature of the Panhandle. In size the hills range from small mounds to ridges 30 to 40 feet high; in shape they are oval, crescent, or elongated, but when parallel they are separated by trough-like depressions. The hills extend in various directions, although, in certain localities, those ranging S. 15° E. appear to predominate. Within the sand-dune regions are broad, shallow, basin-like depressions which are probably large blow-outs covering 1 to 10 acres. There are a few localities containing migratory dunes. One such is on the south side of Canadian River, in western Roberts County, where the dunes are approaching the river. Another is north of Prairie Dog Fork of Red River, in southwestern Donley County.

The sand composing these dunes is derived from two sources, chiefly from the sandstone ledges of either the red beds or the Tertiary disintegrating in place, or from the river sand which in times past has been transported from farther west. These make two classes of sand hills, both of which are frequently found in the same region. The subject is treated more fully under "Geology."

Sand hills occur chiefly in the escarpment region or along the streams, as in western Lipscomb and northern Roberts and Hemphill counties, in Wheeler County south of Mobeetie, and in Donley and Collingsworth counties along the south side of Prairie Dog Fork. A typical sand hill is shown in Pl. IV, *A*.

RIVER PLAINS.

Canadian Valley.—The north central part of the Panhandle of Texas is traversed by Canadian River, which rises in the mountains of New Mexico and in its eastward course crosses the region under discussion in a valley 5 to 20 miles wide cut deeply into the High Plains. The sides of this gorge constitute a portion of the escarpment, with its bad-lands structure of short, sharp ridges, often destitute of vegetation, separated by V-shaped valleys. The flood plan, 1 to 5 miles wide, occupies the bottom of the gorge, 600 feet below the level of the High Plains. The river runs over a sandy bed varying in width from a half mile to more than a mile. It is constantly shifting, excavating sand in one place and depositing it in another.

Wolf Creek Valley.—Wolf Creek has cut a wide valley in the Hi Plains in the northeastern portion of this region. It rises in weste Ochiltree County, at an elevation of 3,300 feet, and descends to 2,3 feet at the Oklahoma line, 45 miles east—a gradient of 21 feet p mile. The width of the valley varies from 1 to 4 miles, and the brea which adjoin it are less rugged than those along the Canadian. Sa hills occur along this creek and its tributaries.

Washita River Valley.—The headwaters of the Washita, which Oklahoma becomes a river of considerable size, rise in Gray Count Tex., in a small creek not differing from many others in this part the plains. It flows eastward in a valley 1 to 3 miles wide acro northern Wheeler County and finally passes from Texas into Rog Mills County, Okla.

North Fork of Red River Valley.—North Fork of Red River ris among the High Plains in the southeastern part of Carson Count and flows east in a broad bend to the north, passing from the Sta almost directly east of its starting place. It flows in a narrow, san choked valley, with sand dunes flanking its south side and with re beds bluffs guarding it on the north for a considerable part of course. This river descends from an elevation of 3,000 feet on t plains to 2,050 feet at the State line, making a descent of 950 f in a passage of 60 miles, or 16 feet per mile.

Elm Fork of Red River Valley.—Elm Fork of Red River, whi becomes a stream of considerable importance in Greer County, Okl is in the Panhandle a mere creek, the greater portion of whose b is entirely dry during the summer. It rises in the escarpment northwest Collingsworth County and, flowing southeast in a de valley cut in the eroded plains, makes its exit from the State 35 mil from its source.

Salt Fork of Red River Valley.—Salt Fork of Red River rises the High Plains in northern Armstrong County at an elevation 3,250 feet, crosses the escarpment, cuts a valley in the eroded plai and after a tortuous course passes from the State in the southeaste part of Collingsworth County at an elevation of 1,900 feet, a desce of 15 feet per mile. It flows in a sand-filled valley, and at times low water the river is a narrow ribbon upon a sand bed half a m wide.

Prairie Dog Fork of Red River Valley.—Prairie Dog Fork of R River crosses Armstrong County in Palo Duro Canyon (not to confused with Palo Duro Creek, in Hansford County), which is miles wide and which has been cut 875 feet through the Tertiary a the red-beds rocks. The river flows in a narrow valley at the bott of this gorge, the sides of which present an alternate precipitous a terraced structure according to the nature of the beds. In Armstro County there are 20 miles of this canyon.

A. SAND HILLS BLOWN FROM CANADIAN RIVER.

B. GYPSUM LEDGE, SHOWING BANDED STRUCTURE.

Minor stream valleys.—Sweetwater Creek, in northern Wheeler County; Spillers Creek, in Collingsworth; Mulberry Creek, in Armstrong; Mammoth Creek, in Lipscomb; Palo Duro and Coldwater creeks, in Hansford; Kit Carson and White Deer creeks, in Hutchinson: Red Deer Creek, in Hemphill, and McClellan Creek, in Gray County, are the largest streams of secondary importance. These smaller streams all form a part of the three major drainage systems, the North Fork of Canadian, the Canadian, and the Red River. Most of these minor streams are periodic, although numerous springs at the base of the Tertiary feed many of the smaller creeks, thus rendering them perennial.

GEOLOGY.

GENERAL RELATIONS.

The general geologic features of the Texas Panhandle are not complex. Most of the rocks belong to two great systems—the Permian and the Tertiary—and there are small amounts of Quaternary deposits, all of which lie nearly level. The lowest formations exposed consist of extensive deposits of red clays and shales known as the red beds, most of which are of Permian age. The greater part of the upper formations are made up of sands, clays, and conglomerates belonging to the Tertiary system. Covering these two members in many places are beds of sand, gravel, and alluvium of Quaternary age. On the geologic map (Pl. V) the distribution of these formations is shown. The relative age and general character of the various deposits are given in the following table:

Geologic formations of the Texas Panhandle.

System.	Name.	Predominant characters.
Quaternary	Alluvium	Loam, sand, and gravel.
	Sand hills	Sand, chiefly in dunes.
	Tule formation	Sand, clay, and gravel.
Tertiary	Blanco formation	Clay, sands, and conglomerates.
	Goodnight formation	
	Loup Fork formation	
Triassic	Dockum formation	Clays, sandstones, and conglomerates.
Carboniferous (Permian).	Quartermaster formation.	Red sandy clay and soft sandstone.
	Greer formation	Red clay, with gypsum and dolomite.

A typical section of the Permian, Triassic, and Cenozoic strata Palo Duro Canyon, 15 miles south of Claude, Armstrong Count Texas, is as follows:

Typical section in Palo Duro Canyon, Texas.

System.	Formation.	Character.	Thickness feet
Tertiary		Tertiary clays, varying in color from almost white to pink; usually with calcite concretions and a few pebbles; occasional harder bands forming terraces.	2
Unconformity.			
Triassic	Dockum	Gray to brown or reddish sandstone. Soft and friable, cross bedded; often changing into conglomerate with lenses of blue and red clay.	
		Variegated clays, maroon, wine-colored, drab, gray, bluish, and red, with ledges of sandstone, sometimes becoming hard enough to form an escarpment; often simply a gray arenaceous shale.	2
Unconformity.			
Carboniferous (Permian).	Quartermaster	Red clay shale, with bands of harder clays, sometimes forming a sandstone, and occasional bands of white or gray clay or sandstone, weathering into characteristic buttes or mounds. Seams of satin spar in the lower part.	2
	Greer	Red clay shale, with ledges of massive white or purple gypsum, interstratified with bands of clay and sandstone.	1
		Total	9

The following sections made on Palo Duro, Tule, and Mulberry canyons in the southwestern part of the region here discussed, where all formations are best exposed, indicate the relative thickness (in feet) of the various beds:

Geologic sections in Palo Duro, Tule, and Mulberry canyons, Texas Panhandle.

System.	Formation.	Palo Duro Canyon.			Tule Canyon. Silverton-Claude road.	Mulberry Canyon. Silverton-Clarendon road.
		Silverton-Clarendon road.	Silverton-Claude road.			
			South side.	North side.		
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Tertiary and Quaternary.	.....	380	220	200	180	240
Triassic	Dockum	110	175	260	165	Eroded.
Carboniferous (Permian).	Quartermaster.	305	280	210	50	160
	Greer	175	195	190	Not exposed.	100
Total		970	870	860	395	500

PERMIAN RED BEDS.

GENERAL STATEMENTS.

The oldest rocks found on the surface in the Panhandle of Texas are the Permian red beds. These rocks occupy a considerable part of the Great Plains from southern Kansas across Oklahoma and Texas as far as New Mexico and Arizona, and outcrop along the eastern flank of the Rocky Mountains as far north as the Black Hills of South Dakota.

In Oklahoma, where the Permian red beds are typically exposed, they have been divided by the writer into five formations, as follows:[a]

Carboniferous	Permian	Quartermaster.
		Greer.
		Woodward.
		Blaine.
		Enid.
	Pennsylvanian.	

The rocks typically exposed around Chandler, now known to be Pennsylvanian, consist of red shales and red or gray sandstones. The Enid formation is composed largely of red clay shales, with an occasional ledge of soft sandstone. The Blaine is characterized by massive

[a] Gould, Chas. N., General geology of Oklahoma: Second Bien. Rept. Oklahoma Geol. Survey, 1902, pp. 42–58. Revised in Water-Sup. and Irr. Paper No. 148, U. S. Geol. Survey, 1905, p. 39.

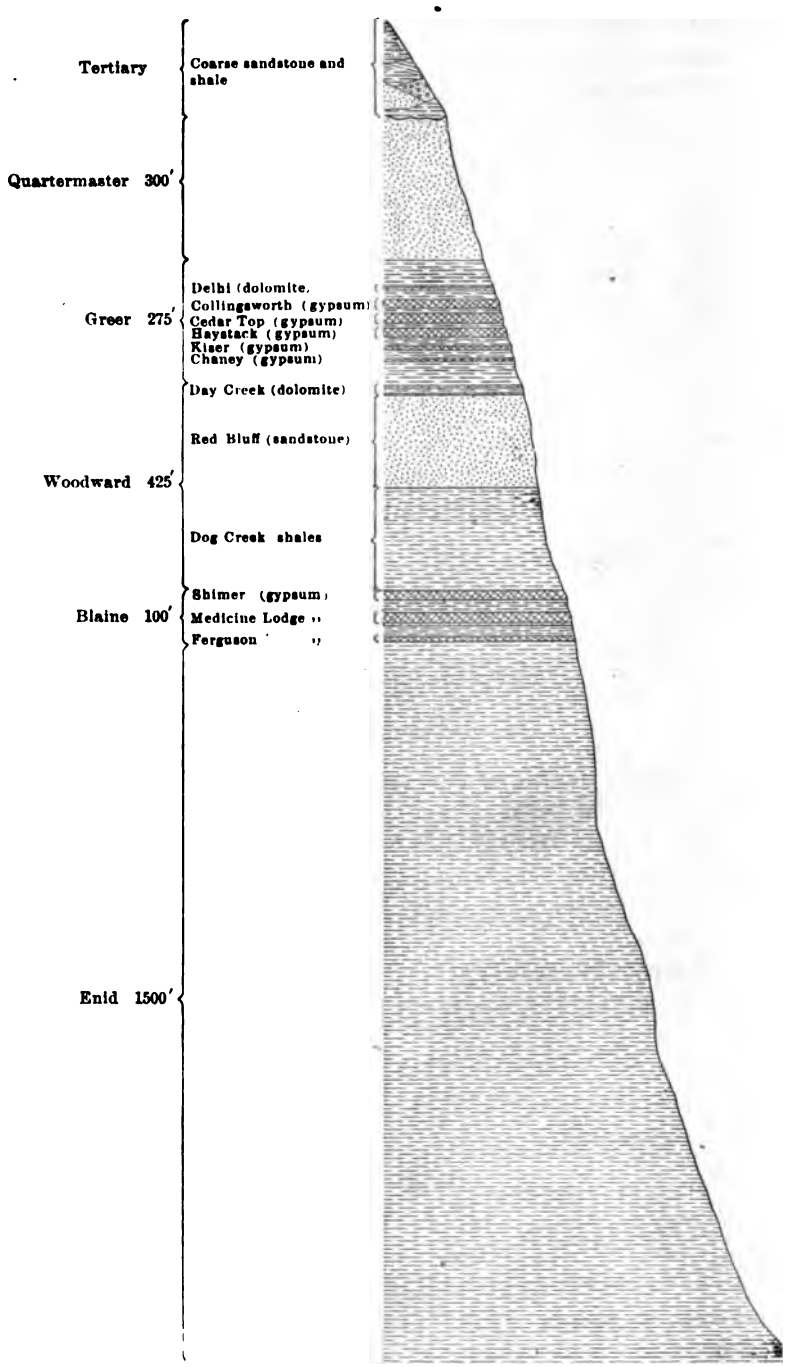


FIG. 1.—Generalized section of Oklahoma red beds. In the above legend "Delhi" s read Mangum, and "Red Bluff" should read Whitehorse.

dges of white gypsum interbedded with red shales. The Wood-ard is made up of red shales and sandstones and a ledge of white olomite. The Greer is also a gypsum formation, in which the ledges re interstratified with red shales. In the Quartermaster the rocks onsist chiefly of red shales and clays, with ledges of soft sandstone. ig. 1 shows the general character and relative thickness of the red eds as exposed in Oklahoma.

Professor Cragin classified the red beds in Kansas and northern klahoma, but he did not examine the lower nor the upper members. e divided the portion that he studied into the Salt Fork and Kiger visions, each consisting of a number of formations.[a]

In comparing this author's classification with the one used by rofessor Cragin it may be said that, in general, the Enid, Blaine, and Woodward formations correspond to his Salt Fork and Kiger. either the rocks near Chandler nor the Greer nor the Quartermaster ormations, as they are now known, were described by Professor ragin.

Professor Cummins divided the red beds into the Wichita, Clear ork, and Double Mountain formations, without, however, sharply ifferentiating them.[b] Doctor Adams, who studied the lower mem-ers of the Texas red beds, found that the divisions made by Profes-or Cummins were unsatisfactory and recommended that they should ot be retained.[c] He has also shown that the Wichita beds in Texas, ike those near Chandler, in Oklahoma, are Pennsylvanian in age.[d] From the best available information it seems probable that the Vichita beds are approximately the equivalent of those near Chand-er, the Clear Fork beds include about the same rocks as the Enid, Blaine, and Woodward formations, and that the Double Mountain eds are practically the same as the Greer and Quartermaster forma-tions. The following table expresses the conditions:

Relationship of formation classifications.

Cummins's classification.	Classification of the writer.	Cragin's classification.
Double Mountain beds	Quartermaster	
	Greer	
Clear Fork beds	Woodward	Kiger division.
	Blaine	Salt Fork division.
	Enid	
Wichita beds		

[a] Cragin, F. W., Permian system of Kansas: Colorado Coll. Studies, vol. 6, 1896, p. 3.
[b] Cummins, W. F., Rept. on the geology of northwestern Texas: Second Ann. Rept. Texas Geol. Survey, 1890, pp. 400–402.
[c] Adams, George I., Stratigraphic relations of the red beds to the Carboniferous and Permian in northern Texas: Bull. Geol. Soc. America, vol. 14, 1903, pp. 191–200.
[d] Ibid., pp. 195–199.

THE PERMIAN IN THE PANHANDLE REGION.

Of the formations of the Permian red beds discussed above, only the Greer and Quartermaster are exposed in the Panhandle of Texas.

Greer formation.—The Greer formation, the lowest member of the red beds found in the Panhandle, has its type exposure in Greer County, Okla., along Elm Fork of Red River, a few miles east of the Texas line. It is here composed of 150 to 200 feet of brick-red clays and shales interstratified with ledges of white, bluish, and pinkish gypsum, with an occasional ledge of magnesian limestone and dolomite. In many places, however, the gypsum beds are entirely wanting or occur as single ledges, while in other localities there are six or more well-marked beds, ranging from 1 to 30 feet in thickness, besides one or two ledges of irregular gray, honeycombed, magnesian limestone, 1 to 3 feet thick. A number of localities in Collingsworth County, Tex., may be cited where these definite gypsum layers occur, but extensive study in the region has shown that all of them are more or less lenticular and do not persist for any considerable distance. Indeed it is not an uncommon occurrence for two or more of these ledges to merge locally by the thinning out of the intervening clays, while at a short distance beyond the gypsums themselves become thin and disappear. In very few parts of the red beds is the tendency to form lenses better exemplified than in the Greer formation. Along North Fork of Red River, just east of the Panhandle line, the writer has named the following members of the Greer: Chaney, Kiser, Haystack, Cedartop, and Collingsworth gypsums and Mangum dolomite.[a] The sequence of the beds is shown in fig. 2.

In view of the facts as presented above, it appears better not to indicate by name those lenses which persist only for a short distance and which can not be correlated in adjoining regions; hence in the present paper no attempt will be made to subdivide the Greer formation.

Because of the lenticular nature of the beds it is not always possible to locate the exact limits of the various subdivisions of the red beds. In general, however, the upper limit of the Greer is placed either at the top of the highest prominent gypsum ledge or at the top of the ledge of magnesian limestone or dolomite, which appears 10 to 20 feet above the highest ledge of solid gypsum.

The gypsum members of the Greer formation abound in caves and sink holes. In Pl. VI, A, is reproduced a photograph of an opening on the surface of a gypsum cave in western Oklahoma. The soft shales which underlie the ledges are easily eroded, and the

[a] Gould, Chas. N., General geology of Oklahoma: Second Bien. Rept. Okla. Geol. Survey, 1902, pp. 55–56.

A. GYPSUM CAVE.

B. SPRING ISSUING FROM A CAVE IN GREER GYPSUM.

gypsum is gradually dissolved by water. It is not uncommon to find a prairie stream of considerable size which disappears in a sink hole. In such case, however, it usually comes again to the surface at no great distance as a spring issuing from a cave (Pl. VI, *B*). These sink holes are of various shapes, with the oblong and circular forms predominating. The oblong sink holes often terminate

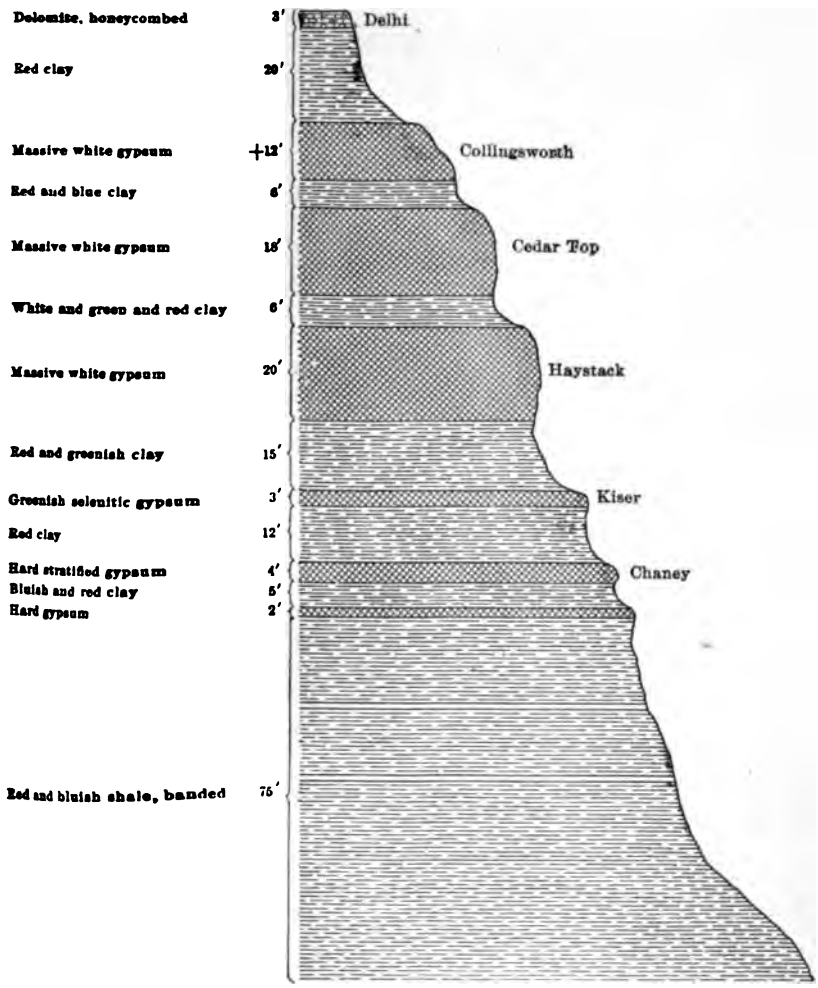


FIG. 2.—Section showing members of Greer formation on Elm Fork of Red River at Salton, Okla. In above legend "Delhi" should read Mangum.

abruptly in caves at one end, while the circular ones exhibit a conical hole in the center, through which the water escapes most freely. These sink holes vary in depth from a few inches to 20 feet or more and are 10 to 100 feet in diameter. In general they are irregularly distributed; in some cases, however, they seem to occur in chains, evidently connected by an underground passage, thus

marking the beginning of a drainage channel. These sink holes are probably formed by the subterranean drainage which dissolves the gypsum and clay below the surface, forming caves which eventually collapse and become stream beds. North of Shamrock, 2 miles from North Fork of Red River, there is a typical sink-hole region in which hundreds of these openings occur in an area of a few square miles.

In various places the members of the Greer exhibit a marked peculiarity of stratification not usually found in the rocks of the plains. The gypsum ledges are here often distinctly laminated, as shown on Pl. IV, *B*. Steep local dips, both anticlines and synclines, are often observed along the sides of a cliff.

A striking peculiarity of the Greer formation is the erratic dip of the gypsum. Frequently in tracing a ledge along a small stream it is found that within a distance of perhaps half a mile the stream descends 50 feet, while the gypsum along the bluff still retains the same height above the water channel. On the opposite side of the stream the same ledge may be traced along another branch until less than a mile away it is 75 feet higher than at the main stream. In other words, the dip of the ledge is toward the stream on both sides, though the ledge is continuous. This peculiarity of dip gives the appearance of irregularly folded strata, yet there has been no general folding whatever. The phenomenon is not easy to understand. Perhaps the most plausible explanation is that the shales have been removed from beneath the gypsum ledges, permitting the latter to sink along the streams into the semblance of a local dip. This fact is exemplified on Pl. VII, *A*.

The Greer formation being the lowest member of the red beds in the Panhandle naturally outcrops low in the stream valleys. It is well exposed along the branches of Red River, particularly on Elm, Salt, and Prairie Dog forks. On Elm Fork it outcrops along the valley of the stream from the Oklahoma line as far west as Shamrock, in southern Wheeler County. Between Elm Fork and Salt Fork the Greer forms the plain as far west as the post-office of Dozier, while along the north side of Salt Fork gypsum ledges appear in the bluffs at intervals, finally disappearing in Donley County a few miles east of the center. South of Salt Fork a strip of sand hills covers the red beds, so that the Greer formation is not exposed north of the divide between Salt and Prairie Dog forks of Red River.

It is in the valley of Prairie Dog Fork of Red River and its tributaries, Spillers and Mulberry creeks, and in Palo Duro Canyon, in Collingsworth, Donley, and Armstrong counties, that the Greer formation attains its typical development in the Panhandle. In this locality it is exposed along the bluffs of the main creeks and caps the slopes of the smaller side canyons that are dissecting the red-beds plain. In Palo Duro Canyon, in particular, the gypsums of the Greer are con-

A UNDERMINING OF GYPSUM LEDGES.

B. EROSION IN THE QUARTERMASTER SANDSTONE IN PALO DURO CANYON.

Tertiary cliffs in the distance.

spicuous; here a number of narrow ravines have been cut out. In this locality creeks sometimes pass into caves and sink holes, and after flowing underground for half a mile or more reappear in a deep canyon. Ledges of white gypsum cap the bluffs and wind in sinuous white lines along the streams.

Quartermaster formation.—Resting conformably upon the Greer are 250 to 300 feet of rocks, consisting for the most part of soft, red sandstones and sandy clays and shales. To this formation the name Quartermaster has been applied, the name being derived from a creek in Day and Custer counties of Oklahoma, along which the rocks are typically exposed. In the lower part of the formation the rocks are chiefly shales, usually red, but sometimes containing greenish bands or layers of clay and often (particularly near the base) a considerable amount of gypsum, which is usually in the form of white or pink satinspar or of rounded concretions. At a higher level the red shales become more arenaceous and not infrequently form a consolidated sandstone, which is rather thin bedded and prone to break into small rectangular blocks. These harder members of the Quartermaster formation often weather into long, narrow buttresses and more or less conical mounds, varying in height from 10 to 50 feet, as shown in Pl. VII, *B*. These conical mounds sometimes occur alone, but more often they appear in groups; occasionally there are hundreds of them on a single quarter section.

The sandstone members are further characterized by marked and very peculiar irregular dips and folds. Strata are often seen dipping at an angle of 20 to 40 degrees, but the dip is irregular, varying in direction to all points of the compass, even on a small area. These local dips often produce slopes which have the character of those formed by normal faults or by general folding. The cause of this phenomenon is not well understood, but apparently the erratic dips are caused by the erosion of some of the subjacent gypsum members of the Greer formation.

In certain parts of the Quartermaster formation there occur beds of hard, white, or pinkish dolomite. One such outcrops on Mulberry Creek, 10 miles southwest of Clarendon, as a ledge 5 feet thick. Another, which caps the bluff at the crossing of Salt Fork of Red River, 3 miles north of Clarendon, is 3 to 5 feet thick, white or pinkish in color, hard or even cherty, with characteristic dendritic markings. When traced east for several miles this ledge is found to be a lens changing into sandstone and sandy shale. Another locality where dolomite occurs is on Antelope Creek, in northwestern Carson County, and along the bluffs north of Canadian River, near Plemons, the county seat of Hutchinson County. The red beds in this locality are provisionally classed as Quartermaster.

Throughout the greater part of this region the Quartermaster formation is overlain unconformably by the Tertiary or Quaternary deposits. In the localities where the Dockum beds are present the upper limit of the formation is located at the line where the color of the shales changes from brick red to maroon or wine color.

In general the Quartermaster formation outcrops in a belt 1 to 5 miles wide at the base of the High Plains. It appears in the southern part of Wheeler County, between Shamrock and Dozier, occupies the northwestern part of Collingsworth County, and follows along the north side of Salt Fork as far west as Clarendon. In the southern part of Collingsworth County the Quartermaster is exposed south and west of Wellington, the county seat. It forms the dissected plain between Memphis and Giles in southern Donley and eastern Armstrong counties. Along Palo Duro Canyon, in southwestern Armstrong County, it exhibits a maximum thickness of 300 feet and forms the top of the intracanyon terrace, just above the Greer gypsum ledges.

The red beds are exposed along Canadian River in northern Carson and southern Hutchinson counties. The most typical exposures are along Dixon and Antelope creeks, in Carson County, where 250 feet appear in vertical section. They contain some beds of dolomite and gypsum. These beds do not seem sufficiently uniform and persistent to warrant giving them definite names, yet they are more extensive than similar beds that occur in other portions of the formation. It is probable that a detailed study will reveal that these beds extend farther to the west along Canadian River. Plicated structure, noted elsewhere, is exemplified in this region. The following section was made in southwestern Hutchinson County, 2 miles from the mouth of Antelope Creek:

Section of red beds on Antelope Creek, Carson County, Tex.

	Feet
Red clays, with sandy shale	[illegible]
Gray sandstone	[illegible]
Red clay	[illegible]
Gray dolomite, weathers out in blocks which are scattered over talus slope (this ledge forms a terrace)	[illegible]
Red clay	1[illegible]
Gypsum, bluish in places; a fairly persistent uniform ledge	[illegible]
Red clay, lower portion covered	[illegible]

For lithological reasons these beds as a whole are considered as belonging to the Quartermaster formation.

Near the middle of the Quartermaster formation, as exposed in Collingsworth and Hall counties, there is a ledge of rather hard, red or pinkish, more or less oolitic sandstone, which on weathering gives rise to a number of flat-topped buttes and ridges. Of these the most typical are Rocking Chair Mountains (Pl. VIII, *A*), southwest of

A. ROCKING CHAIR MOUNTAINS.

A hill capped by the Dozier sandstone.

B. SANDSTONE MEMBER OF THE DOCKUM FORMATION IN PALO DURO CANYON.

ıamrock; Antelope Butte, near the head of Elm Fork of Red River: ozier Mounds, near Dozier post-office, and 'Possum Peaks, Twin ounds, and Ragged Top, a few miles farther west of Dozier. Be-ɔeen Salt and Prairie Dog forks of Red River, in the vicinity of emphis, in Hall County, these buttes are conspicuous. Hogback utte, 8 miles south of Memphis, is a noted landmark. These buttes ɔsist for an unknown distance south of Salt Fork of Red River.

From the sandstone on Antelope and Dozier mounds, Dr. J. W. ɔede identifies fossils belonging to the following genera: *Dielasma*, *hizodus*, *Allorisma*, *Pleurophorus*, *Edmondia*, *Aviculopecten*, *Lei-ɔteria*, *Capulus?* (*Lepetopsis?*), *Loxonema*, *Strophostylus*, *Murchi-nia*, *Pleurotomaria*, and *Worthenopsis*; indicating the Permian age the sandstone.

TRIASSIC RED BEDS.

Dockum formation.—The upper part of the Texas red beds was scribed by Professor Cummins under the name of Dockum beds,[a] d afterwards by Drake.[b] This formation, which is composed ɔgely of clays, sandstones, and conglomerates, underlies practically l of the Staked Plains of Texas and southeastern New Mexico. ccording to Drake,[c] the Dockum beds average 200 feet in thickness, d may be divided into three members, as follows: (1) A lower bed of ndy clay 0 to 150 feet thick, (2) a central bed or beds of sandstone, nglomerate, and some sandy clay 0 to 235 feet thick, and (3) an ɔper bed of sandy clay and sandstone 0 to 300 feet thick.

Along Palo Duro Canyon in Armstrong and Briscoe counties, here this formation was studied by the writer, it is difficult to vide it into recognizable members. The formation abounds in local ıconformities with clay, sandstone, and conglomerate lentils, with oss-bedded structure, and other features indicative of shallow-water ɔposition. In places the lower portion is made up of red, maroon, wine-colored clays, while at higher horizons there are more or ss lenticular sandstones and conglomerates, as shown in Pl. IX, *B*. ı weathering, the sandstones of the Dockum beds give rise to unique ɔsion forms; the harder members protect the softer shales beneath d produces pillars, chimneys, toadstools, and other unusual figures, ne types of which, exposed in Tule Canyon, 6 miles northwest of lverton, are shown in Pl. IX, *A*.

The lithologic characters which justify the separation of the ɔckum beds from the Permian are, (1) the gray and brown color the sandstones and conglomerates and the abundance of the latter;

Cummins, W. F., First Ann. Rept. Texas Geol. Survey, 1899, pp. 189–190; Second ı. Rept., 1900, pp. 424–428.

Drake, N. F., Stratigraphy of the Triassic formations of northwest Texas; Third ı. Rept. Texas Geol. Survey, 1901, pp. 227–247.

Ibid., pp. 229–233.

(2) the maroon, wine-colored, and yellow shales and clays, and (3) the extensive cross-bedding and local unconformities of the various members. Whether or not the Dockum formation is conformable throughout with the subjacent Quartermaster formation is still an open question. There is often local unconformity between the two formations, but on the other hand there are localities in which the brick-red shales and argillaceous sandstone of the Quartermaster grade so imperceptibly into the wine-colored shales and gray-brown conglomerates of the Dockum that the closest search fails to reveal the line of separation between them.[a]

Concerning the age of the Dockum formation it may be said that vertebrate fossils, found in these rocks and described by Cope,[b] as well as certain new forms of *Unios* named by Simpson,[c] indicate that the beds belong to the Triassic. In all, seven species of vertebrates and four of pelecypods have been secured from this formation.

TERTIARY AND QUATERNARY FORMATIONS.

REFERENCE LIST OF PUBLICATIONS.

For extended discussions of the Tertiary rocks of various parts of the Great Plains the reader is referred to the following publications:

Cummins, W. F., Notes on the geology of northwest Texas: Fourth Ann. Rept. Texas Geol. Survey, 1893, pp. 190–203.

Dumble, E. T., Cenozoic deposits of Texas: Jour. Geol., vol. 2, No. 6, 189 pp. 549–563.

Hay, Robert, Water resources of a portion of the Great Plains: Sixteen Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 569 et seq.

Haworth, E., Physical properties of the Tertiary: Univ. Geol. Survey Kansas, vol. 2, 1897, pp. 247–284. Underground waters of southwestern Kansas: Water-Sup. and Irr. Paper U. S. Geol. Survey No. 6, 1897.

Darton, N. H., Report on the geology and water resources of Nebraska west of 103d Mer.: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1899, pp. 719–78 Also in Prof. Paper U. S. Geol. Survey No. 17, 1903.

Darton, N. H., Rept. on the geology of the central Great Plains: Prof. Paper U. S. Geol. Survey No. 32, 1905.

Johnson, Willard D., The High Plains and their utilization: Twenty-fir Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, pp. 601–741. Twenty-second Ann Rept. U. S. Geol. Survey, pt. 4, 1902, pp. 631–669.

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[a] Since the above was written opportunity has been afforded for studying these beds the western part of the Panhandle of Texas, both on upper Palo Duro Canyon and along the valley of Canadian River. The writer finds that in this region the Triassic everywhere separated by a pronounced unconformity from the subjacent Permian red bed and that it is clearly divisible into two formations, each consisting of well-marked members. These formations and members will be described in a forthcoming water supply and irrigation paper.

[b] Cope, E. D., Vertebrate remains from the Dockum Terrane of the Trassic system Fourth Ann. Rept. Texas Geol. Survey, 1903, pp. 11–17.

[c] Simpson, C. T., Descriptions of four new Triassic Unios from the Staked Plains of Texas: Proc. U. S. National Mus., vol. 18, No. 1072, 1896, pp. 381–385.

A. EROSION FORMS IN THE DOCKUM SANDSTONE IN TULE CANYON.

B. SANDSTONE AND SHALE MEMBER OF THE DOCKUM FORMATION.

Showing lenticular nature of the strata.

STRATIGRAPHY.

General statement.—After the deposition of the Permian and Triassic red beds in the Panhandle region the area was elevated and for a long period of time the land was extensively eroded. Farther south and west extensive deposits of Cretaceous rocks rest on the red beds, but in the part of the Panhandle under discussion Cretaceous formations are absent.

Resting uncomformably upon the eroded surface of the red beds throughout the region described in this paper are extensive deposits of the Cenozoic age—Tertiary or Quaternary—which make up the rocks of the High Plains. These formations, which consist largely of loosely consolidated clays, sands, and conglomerates, typically white, but varying locally into gray, buff, brown, or other colors, constitute the "Tertiary grit" and the "Tertiary marl" or "mortar beds" of the Kansas geologists. In Nebraska, Mr. Darton subdivides the beds of approximately this age into the Arikaree and the Ogalalla. In the Panhandle of Texas Professor Cummins has distinguished four horizons, basing his classification upon the evidence afforded by vertebrate fossils obtained in the different beds and identified by Professor Cope.[a]

The following table sets forth the names of the members as used by Professor Cummins, the geologic age, and the number of species Professor Cope found in each:

Vertebrate fossils distinguishing four horizons in the Panhandle of Texas.

Period.	Epoch.	Formation.	Number of species.
Quaternary	Pleistocene	Tule (*Equus* beds)	10
Tertiary	Pliocene	Blanco	16
	(Transition)	Goodnight	8
	Miocene	Loup Fork	17

Loup Fork formation.—The term "Loup Fork" has long been used to include a series of rocks, usually considered later Miocene in age, which are extensively exposed on the Great Plains, particularly in Colorado, Nebraska, Kansas, Oklahoma, Texas, and New Mexico. The rocks consist largely of sands, clays, and conglomerates, the latter made chiefly of smooth water-worn pebbles presumably derived from the Rocky Mountains. The thickness of the deposits varies, but the maximum is several hundred feet. The Loup Fork beds constitute the lowest Tertiary formation known to exist in the Panhandle. According to Professor Cummins these beds do not extend

[a] Fourth Ann. Rept. Texas Geol. Survey, pt. 8, 1893, pp. 18–86.

farther south along the eastern edge of the Llano Estacado than the Prairie Dog Fork of Red River.[a] On Mulberry Creek, 12 miles west of Clarendon, where Cummins and Cope obtained the fossils identified by the latter, the Loup Fork beds are 30 feet thick and "composed of alternating beds of bluish and almost pure white sand."[b]

Goodnight formation.—This division, named by Professor Cummins from the town in Armstrong County, Tex., consists of calcareous and arenaceous clays, sands, and heavy conglomerates. Lithologically, it is practically impossible to differentiate these beds from those of the Loup Fork or Blanco, and it is only by means of fossils contained in them that the beds are known to be of different age. Professor Cope identified eight vertebrates from these beds and assigned them to an age intermediate between the Loup Fork and the Blanco.[c] Professor Cummins states that the Goodnight beds have extensive development south of Mulberry Creek. The maximum thickness as given by him is approximately 150 feet.[d]

Dall, on the authority of Dumble, has called these beds Palo Duro. He classes them as transitional between the Miocene and Pliocene, and says: "These beds, identified in western Texas by Scott as transitional, also had the absurd name of Goodnight applied to them."[e] Certainly no one who has ever been in that portion of the Panhandle would consider the name of Goodnight as absurd, for it is the name of one of the largest of the old-time cattle ranches, as well as of a good-sized town, the seat of a flourishing college.

Blanco formation.—Professor Cummins gave the name Blanco beds to those Tertiary rocks which rest unconformably upon the Dockum conglomerate at the type locality of the latter—i. e., at Dockum, Dickens County, Tex. Vertebrate fossils from that region have been identified by Professor Cope, who states that "the horizon is more strictly and nearly Pliocene than any of the lacustrine terranes hitherto found in the interior of the continent."[f] The rocks consist of alternating layers of sand, clay, and diatomaceous earth, approximately 160 feet in thickness.

Tule formation.—These beds, described by Professor Cummins[g] and by Professor Cope, were assigned by the latter to the *Equus*-bed

[a] Cummins, W. F., Notes on the geology of northwest Texas: Fourth Ann. Rept. Texas Geol. Survey, 1893, p. 203.

[b] Ibid., p. 204.

[c] Cope, E. D., Vertebrate fauna of the Loup Fork beds: Fourth Ann. Rept. Texas Geol. Survey, pt. 8, 1893, p. 46.

[d] Cummins, op. cit. pp. 201–202.

[e] Dall, Wm. H., Table of North American Tertiary horizons, etc.: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, p. 338.

[f] Cope, E. D., Vertebrate fauna of the Blanco beds: Fourth Ann. Rept. Texas Geol. Survey, 1893, p. 47.

[g] Cummins, op. cit. pp. 199–200.

horizon of the early Pleistocene, on account of vertebrates from Tule Canyon in Swisher County. In general, the statement made by Professor Cope that "*Equus* beds form the superficial formation of the country at various points on the Staked Plains and about its eastern escarpment,"[a] may be considered as accurate. However, the *Equus* beds are by no means confined to the top of the Llano Estacado, but occur in other localities as well, notably north of Canadian River. These rocks consist of coarse sand, clay, and gravel, with variable thickness.

Age of beds.—It is the experience of the writer, after ten seasons spent in studying these deposits in Kansas, Oklahoma, Texas, and New Mexico, that it is practically impossible to separate either the Tertiary or Pleistocene deposits of the plains into mappable formations. From the bottom of the Loup Fork to the top of the *Equus* beds the general character of the rocks changes so constantly and with such extreme irregularity that they can not for the most part be differentiated in the field. Sections made at about twelve points in eastern Colorado, western Kansas, western Oklahoma, and in the Panhandle of Texas show such a marked similarity of structure that without the evidence of fossils it is impossible to determine whether the rocks belong to the Miocene, the Pliocene, or the *Equus* beds. Even Professor Hay, who studied these rocks in Kansas and applied to them the descriptive terms "Mortar beds," "Tertiary grit," "Tertiary marl," etc., did not succeed in differentiating them into definite horizons. If it were possible to distinguish formations stratigraphically, the matter of classification would be greatly simplified, but in the light of present knowledge, it seems not only inexpedient but even impossible to differentiate them structurally. In view of these facts, therefore, the general term Tertiary will be used to include the Loup Fork, the Goodnight, the Blanco, and in most cases also the Tule or *Equus* beds. The *Equus* beds are classed with Tertiary chiefly, as stated above, because these beds can not be distinguished in the field, nor, indeed, by any other means than that of vertebrate fossils, which are present only in scattered localities.

ORIGIN OF THE TERTIARY DEPOSITS.

With regard to the origin of the Tertiary deposits of the Great Plains two general theories have been advanced. The earlier geologists who studied these rocks considered them lacustrine in origin: Professor Marsh, for instance, described a great Pliocene lake covering practically the entire Great Plains area, in which deposits 1,500 feet thick were laid down.[b] Professor Cummins, in speaking of the

[a] Cope, E. D., Vertebrate fauna of the Blanco beds: Fourth Ann. Rept. Texas Geol. Survey, 1893, p. 75.

[b] Marsh, O. C., Amer. Jour. Sci., vol. 9, Jan., 1875, p. 52.

Goodnight beds, says, "They seem to have been deposited in a lake much more extensive to the south than the Loup Fork, which latter seems to have had its southern termination here" (at Mulberry Canyon).[a] Professor Cope has already been quoted regarding "Lacustrine terranes." Professor Hay accepted the lake theory, although he did not account for the formation of these supposed bodies of water.[b] Later investigations, however, have led to the opinion that it is to fluviatile rather than to lacustrine agencies that we must look for the origin of the Tertiary deposits.

Professor Haworth, in discussing the Kansas Tertiary,[c] observes: "The relative positions of the sand, the gravel, and the clay of the Tertiary over the whole of Kansas * * * correspond much better to river deposits than to lake deposits. The irregularity of formation succession, the limited lateral extent of the beds of gravel, sand, and clay, and the frequent steepness of the cross-bedding planes, all correspond to river deposits. * * * The materials themselves have many indications of river deposits and a very few of lake deposits."

Mr. Johnson, in his report on "The High Plains and Their Utilization," expresses the opinion that "The structure, an uneven network of gravel courses and elongated beds of sand penetrating a mass of silt and sand-streaked clay, is the normal product of desert-stream work under constant desert conditions. The coarse material is not regarded as the product of necessarily strong-running streams and the fine material of sluggish streams, in alternating epochs of humid and dry climate or of high and low inclination of slope, but as the simultaneous product of branching streams of the desert habit, here running in a channel and there spreading thinly."[d]

The only point at issue among these writers seems to be whether the cause of the deposition of the material by the streams is to be sought in climatic changes which produced alternate periods of aridity and humidity, or in deformation movements of the earth's crust by which the eastern part of the Great Plains was elevated and the gradient of the streams lessened. With regard to this matter the writer does not express an opinion. The subject has been discussed by Johnson, to whose article the reader is referred.[e]

GENERAL CHARACTER OF THE TERTIARY DEPOSITS.

It has been stated already that the greater part of the rocks consists of clays, sandstones, and conglomerates with clays predominat

[a] Cummins, W. F., Notes on the geology of northwest Texas: Fourth Ann. Rept. Texas Geol. Survey, 1893, p. 201.

[b] Hay, Robert, Water resources of a portion of the Great Plains: Sixteenth Ann. Rep. U. S. Geol. Survey, pt. 2, 1895, p. 571.

[c] Haworth, E., Physical properties of the Tertiary: Univ. Geol. Survey Kansas, vol. 1, 1897, p. 283.

[d] Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, 655.

[e] Ibid., chap. 2, p. 612-656.

A. EDGE OF TERTIARY ESCARPMENT.

Showing alternation of hard and soft beds.

B. PECULIAR WEATHERING OF TERTIARY CLAY IN PALO DURO CANYON.

ing. In color the clays are normally white, so white that when exposed they are frequently spoken of as "gyp" cliffs or "chalk" cliffs, although they contain neither gypsum nor chalk. However, the color of the clays is not invariably white; it often grades into the various other light tints. In structure the clay is usually so soft that it may be crushed with the fingers; but, on the other hand, the more calcareous members are frequently indurated and make a fair quality of limestone. Occasionally beds are found full of white calcareous lumps or concretions, which give to the rock a mottled appearance. The lime often cements the clay together in the form of elongated concretions, which, on weathering, have a resemblance to stalactites, as shown in Pl. X, *B*, and form what one author calls "pipy" concretions.[a]

Sand beds and ledges of conglomerate also constitute a considerable part of the Tertiary and Quaternary. The sand is usually in smooth, rounded, white or yellowish grains and the material is of quartz. The conglomerate is made up typically of smooth water-worn pebbles, usually composed of quartz, granite, porphyry, and other igneous rocks, varying in size from sand grains to bowlders as large as a peck measure. These pebbles most commonly occur in beds or layers sometimes as much as 25 feet thick, but often they are intermingled with fine sand and sometimes sprinkled through the clay members.

In a number of localities the gravel beds at the immediate base of the Tertiary contain considerable numbers of water-worn *Gryphæa* shells of lower Cretaceous age. It has been stated that at the present time there are no Cretaceous rocks exposed between the red beds and the Tertiary deposits in this part of the Panhandle, but that extensive Cretaceous deposits are found along the southern and western edges of the Llano Estacado. Whether these shells were derived from the lower Cretaceous rocks in place, or were transported by streams from beds farther west, it is impossible to determine, but in the light of available data the latter supposition seems probable.

The relative proportion of the different rocks enumerated above varies with the locality, but it is probable that three-fourths of the Tertiary and Pleistocene material exposed along the eastern edge of the Staked Plains is some form of clay, silt, or marl, the other one-fourth being sand or conglomerate. Farther north, in Kansas and Nebraska, the proportion of coarser material is relatively larger, often being more than one-half.

In all places on the plains, so far as known, these materials are arranged in a heterogeneous manner—the clays, sand, pebbles, silt, conglomerate, and other forms of rock occurring indiscriminately and without similarity of position. In one place a section of a hill

[a] Darton, Nelson H., Report on the geology and water resources of Nebraska west of 103d Mer.: Prof. Paper U. S. Geol. Survey No. 17, 1903, p. 25.

shows nothing but clay and silt; half a mile away beds of sandstoı and gravel occur; and still farther away the section reveals litt besides sand and conglomerate. (Pl. X, *A*, *B*, exhibits typical Te tiary structure.)

SAND HILLS.

There are two general classes of sand hills in the Panhandle, tho derived from the disintegration of rocks in place and those blown b the winds from some stream channel. The sand hills of disintegr tion occur usually either along the base of the escarpment at the fo of the High Plains or along the divide between two river system The material of which these sand hills are composed has been largel derived in place by the disintegration of Tertiary rocks. As the cla and silt which make up a considerable part of the Tertiary deposit were removed by the action of water the sand and gravel remaine behind and the finer materials have been shaped by the wind. I each of the four eastern counties of the Panhandle there are coı siderable areas of sand hills which have been formed in this manne In Lipscomb and Hemphill counties sand hills occur along Wolf Cre and on the divide between that stream and Canadian River. Mu of Wheeler County is covered with sand hills, particularly in t region between Sweetwater Creek and North Fork of Red River. Collingsworth County there is a region 10 to 15 miles wide south Salt Fork, extending entirely across the county, composed wholly these sand hills, and in southeastern Donley County there are lar areas covered with sand hills.

In the second class of sand hills are those formed of wind-blov sand derived from the stream channels. In the Panhandle regi they seem to occur indiscriminately on both the north and south sid of the various rivers, usually along the flood plain between the cha nel of the stream and the bluffs. Hills of this character, which a composed of fine white or yellowish quartz grains, are usually barr of vegetation, as shown in Pl. IV, *A*. They are present alo practically all the larger streams, particularly along Canadian Riv and Salt Fork of Red River. Migrating dunes are not uncomm

ALLUVIUM.

Along all the large streams in this region there have been deposit materials of greater or less thickness that have been brought by t streams from higher levels. In the valley of Canadian River is broad belt of bottom land made up largely of alluvium, which he consists chiefly of fine sand and clay mixed with decayed orgar matter and occasional coarser gravels, the whole constituting a sanc loam. As much of the clay is derived from the red beds, the loa often partakes of a reddish color. Along all the small strea

emptying into Canadian River are bottom lands or flood plains composed of practically the same material, and there are deposits along the various tributaries of Red River. Along North Fork and Salt Fork the bottom lands are from half a mile to a mile wide.

WATER RESOURCES.

UNDERGROUND WATERS.

GENERAL CONDITIONS.

The underground waters of the Panhandle of Texas may be discussed under two general heads—red-beds waters and Tertiary waters. Under the latter head is included water from the sand hills. The water of the red beds occurs chiefly on the eroded plains at the foot of the escarpment in the southern and eastern part of the region. The water of the Tertiary is found on the High Plains and in the escarpment regions—that is, on the greater part of the area under discussion. The water of the red beds is limited in amount and usually impregnated with mineral salts, particularly gypsum ($CaCO_4$) and common salt (NaCl), so that it is often unfit for general use, while the Tertiary water is uniformly abundant and almost always pure and wholesome. So different both in quality and quantity are the waters from these two horizons that it seems best to discuss them separately.

WATER FROM THE RED BEDS.

Character.—Wherever the Permian red beds are exposed the water is unsatisfactory in quality, although it ordinarily is plentiful. Water from the red beds generally contains appreciable amounts of mineral salts, which in many cases are so abundant as to render it unfit for general use. To all this salt-impregnated water the common term "gyp" water is applied. In point of fact, however, much of the water does not contain any considerable per cent of calcium sulphate. A number of other mineral salts are found in the red beds, the most abundant of which are sodium chloride, sodium sulphate, sodium carbonate, magnesium carbonate, magnesium sulphate, calcium chloride, and sodium borate, in about the order named. In some instances all of these salts are found in the water of a single well, but in most cases only two or three of them appear in appreciable quantities.

It must not be understood, however, that all the water from the red beds is bad, for there are numerous localities where soft and pure water is found. Especially is this true of the localities where the water is obtained in the Quartermaster formation, which, as has been stated, consists largely of soft sandstones and sandy shales. In

this formation but little gypsum occurs, and the proportion of the other mineral salts enumerated above is not as great as in the rocks of the Greer formation. The general statement may be made, however, that water from the red beds is not good water.

Occurrence.—Water in the red beds is usually found under one of two conditions: first, in sandstones or sandy clay beds, and second, in underground veins, either joints in the clay or in gypsum caves. As has been stated, the red beds consist largely of red clay shale with occasionally interbedded members of sandstone and gypsum. In part the clays are composed of very fine-grained material which is practically impervious to water. Frequently they contain a high proportion of sand, in which case the interstices between the sand and clay particles are sufficiently wide for the seepage of water, and it is from beds of this character that perhaps the greater part of the wells obtain their permanent supply. In many parts of the red beds, especially in the Quartermaster formation, the arenaceous clay beds become a true sandstone and the relatively large spaces between the sand grains afford ready passage for water.

Many of the wells, however, find their supply not in sand nor even in sandy shales, but, if the testimony of drillers is given credence, in joints in the red clay. Those who have had experience in drilling wells agree in stating that while the greater part of the water in the red beds is found in sand, many of the wells penetrate nothing but the red clay. It is not uncommon for the drill to strike a so-called vein in the clay, in which the flow is so strong that the water rises many feet before the tools can be lifted. It has been said that the red beds abound in sink holes and caves, and that from many of the caves springs issue. In a number of cases the drill has been known to penetrate these caverns, which thus become reservoirs for the wells. The depth of wells in the red beds varies from 20 to 190 feet, averaging 60 feet.

WATER FROM TERTIARY ROCKS.

Character.—Almost without exception the water obtained in the Tertiary and sand-hills deposits of the Great Plains is good. Analyses of water from a number of wells and springs in these formations in Nebraska, Kansas, Oklahoma, and Texas have almost invariably shown that the water contains little or no harmful mineral salts. There are to be found small amounts of calcium sulphate, calcium chloride, calcium carbonate, magnesium carbonate, and sodium bicarbonate in the water of some of the wells, but the average amount of mineral salts in 7 samples was but 15 grains per gallon. The water on the plains is almost universally soft, pure, and wholesome, suitable for household and stock use.

Occurrence.—In order to appreciate the underground-water conditions of the High Plains, an understanding of the rocks from which the water is obtained is necessary. As has been shown under "Geology," pages 25–31, the Tertiary deposits, several hundred feet thick, which cover this region, consist chiefly of alternating layers of clay, sand, and gravel. It is generally believed by geologists that the material which comprises these rocks was derived largely from the Rocky Mountains, and that it was spread out in the beds of streams which in time past flowed from the mountains and were lost on the plains. These streams left deposits, now of sand, now of gravel or clay, and now of pebbles, which, in time, were covered by other deposits, sometimes of the same, but more often of other material. This process was continued until several hundred feet of alternating beds of the various kinds of rocks were deposited. From this it will be understood that the greater part of the beds must necessarily be irregularly lens-shaped in cross section, and in most cases will not be found continuous over large areas. In some places the greater part of the thickness consists of clay or silt, while in other localities sand and gravel predominate. In general, it is observed that the deposits near the base of the Tertiary have a greater proportion of the coarser material, consisting of sand and gravel beds, and that at a higher level they have clays and silts in greater abundance.

Most of the water of the High Plains is known as "sheet water." This is a term almost universally used in the western part of the United States to indicate any fairly constant supply of water at a more or less uniform depth beneath the surface. The term "underflow" is sometimes used to indicate practically the same phenomenon. The general impression seems to be that at some depth beneath the surface there is a regular "sheet" or "lake" of water, which if tapped by a well will yield a constant supply. In some places two or even three "sheets" are supposed to exist, and the expression "first sheet" and "second sheet," or "first water" and "second water" are common. Another prevalent notion is that the water in these "sheets" is constantly flowing, stream-like, beneath the surface, an idea disclosed by the expression "the underflow is to the south," or "the underflow is east." Much of this theory, however, is erroneous and not based on valid conceptions of the conditions found in the nature and relations of the water-bearing beds. Rounded grains of sand and gravel do not lie close enough together to fill all of the space, but have interstices between them. These pores or spaces are minute reservoirs for the water which, in its passage through such materials, seeps from one of these minute reservoirs to the next, and thus very slowly flows along underground. This movement is called "underflow," but it is not nearly so rapid as popularly sup-

posed. Experiment has shown that even along stream beds, such as the Arkansas River in western Kansas, the rate of underflow does not average more than 10 feet a day.[a] On the High Plains, where the gradient is exceedingly low, it is doubtful if the water moves more than this distance in a year. This is a point, however, upon which there are practically no data, and estimates may be misleading.

Dry ground, according to the theory just advanced, is ground the pores of which contain no water, while wet or saturated ground is that in which the pores are filled. Since water tends to sink to the lowest levels, there is in most regions a certain, but variable, thickness of beds filled with water in what is technically known as the "zone of saturation." The upper surface of this zone of saturation is called the "water table," and this is often identical with the popular phrase "sheet water." Since water moves so slowly underground, this water table often becomes approximately similar in contour to

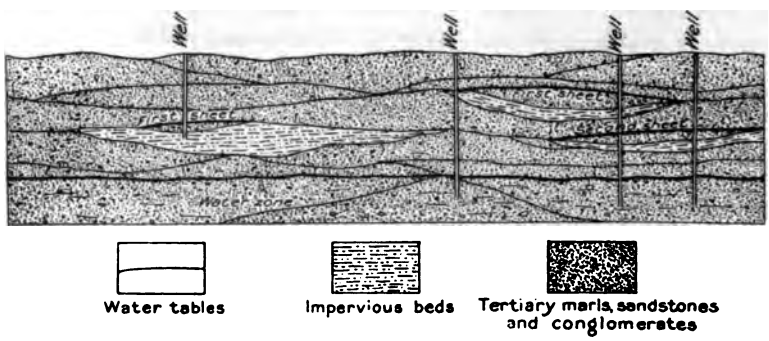


FIG. 3.—Ideal section of Tertiary, showing first and second sheet water.

the surface of the ground, being high on the divides and low near the streams where the water may escape in springs.

Attention has been called to the conditions under which these beds were laid down. As originally deposited they must have had an irregular outline and surface, especially when laid down in swamps or lakelets. Where the material is clay or very fine sand its interstices are very minute and practically impervious to water. Such fine deposits are often overlain by sand and gravel in basins or channels, and these in turn by other fine-grained deposits in varying succession, so that the alternation in water-bearing and impervious beds is most irregular, as shown in fig. 3. If such deposits are penetrated by a well the first sand encountered will supply water, the quantity of which depends upon the size of the water-bearing deposit, its coarseness of grain, the height of its edges, etc.; in the next coarse sand bed a second water stratum is found, and so on until finally the main water table is penetrated. This may be considered a probable

[a] Slichter, Charles S., The motions of underground waters: Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, pp. 41–43.

explanation of the "first and second water," "first and second sheet," etc. It also possibly accounts for conditions similar to the one found near Groom, Gray County, where records obtained from a relatively small area show well depths ranging from 300 to 360 feet, except in one well where water is obtained at 228 feet. This shallower well probably finds its source of supply in one of these buried basins.

Wells throughout the Tertiary area usually secure water at depths varying from 20 to 500 feet. On the High Plains the average of twenty wells, taken at random from half a dozen counties, was 258 feet. The deepest wells are found along the line of the Santa Fe Railroad on the high divide south of Canadian River, in Carson and Gray counties, where the wells are from 350 to 500 feet deep. On the High Plains in Hansford, Ochiltree, and Lipscomb counties, north of Canadian River, the average depth is 240 feet. In Armstrong County, along Prairie Dog Fork of Red River, the average depth is less than 200 feet. In certain parts of the region, notably in Hansford and Carson counties, the driller sometimes fails to obtain a water supply, and instances are reported where the entire thickness of the Tertiary has been penetrated without finding an adequate amount. It is the experience of drillers that if the "red clay" (evidently red-beds clay) is encountered without finding a sufficient amount of water, it is useless to go deeper.

SOURCE OF THE UNDERGROUND WATER.

Local precipitation is the source of the underground water of the High Plains. The rainfall at Amarillo, Tex., a few miles west of the region here discussed, averaged 21.94 inches annually for a period of twenty years.

Rainfall on the surface of the earth is disposed of chiefly by evaporation, run-off, and sinking, or seepage into the ground. It is estimated that in general the amount of water disposed of in each of the three ways is about equal, but the relative amounts in different regions depend upon several local conditions. For instance, on a steep slope the greater part runs off; in a warm, arid climate the greater part evaporates, while in loose soil the greater part soaks in.

On a considerable part of the Great Plains, where the surface is level and the drainage systems undeveloped, there is no run-off, and the rainfall is either absorbed by the ground or evaporates. After a rain the water which does not evaporate immediately or is not absorbed by the ground accumulates in broad, shallow depressions on the surface, known as "buffalo wallows," or "lakes," and there remains until it evaporates. Johnson estimates that not more than 3 or 4 inches annually soak into the ground, an amount which would not saturate more than about 1 foot of sandy strata.[a] This estimate

[a] Johnson, Willard D., The High Plains and their utilization: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 4, 1902, p. 646.

of the amount of water absorbed seems rather small, but in all probability not more than 6 inches of rainfall are added to the ground water each year.

THE WATER TABLE.

As stated on page 34, the "water table" or "wat er plane" is the subsurface plane beneath which t e ground is saturated with water; in other words, t e level at which the top of the ground water stand s It varies constantly from place to place, from ye to year, and even from day to day. It is supplie chiefly from rainfall and is lowered when the wate is removed, as, for instance, in the case of spring by artesian wells, or by heavy pumping. Ordinaril it is at a considerable distance below the surface but occasionally it reaches the surface level, as in springs, swamps, or marshes.

On the High Plains the water table is located at the upper point of saturation of the pervious beds. Well records show that this water level for the High Plains, as a whole, averages approximately 250 feet below the surface. So far as known, this level is fairly constant, the amount of water taken away by springs and wells being approximately equaled by the amount added each year by precipitation. Fig. 4 shows an east-west section of the plains and the position of the water table.

FIG. 4.—East-west section of High Plains, showing position of water table.

USE OF WINDMILLS.

As the Panhandle is chiefly a grazing country, most of the wells have been put down for the purpose of furnishing water for cattle. On the greater number of the larger ranches wells are located 2½ to 3 miles apart, and windmills are almost universally used to bring the water to the surface.

Often upon the prairie the only object in view to indicate that the locality is inhabited is a solitary windmill. These mills are placed upon towers 20 to 30 feet high, constructed of wood or steel. All types of factory-made turbines are used, but the steel mill with a wheel 8 to 10 feet in diameter seems to be most effective for general purposes. Larger wheels, some even 20 feet in diameter, are employed to elevate the water for the entire supply of some of the larger towns, as, for instance, Panhandle and Ochiltree. (Pl. XI, A.) On the

A. WINDMILL AND TANK AT OCHILTREE, TEX.

B. TYPICAL WINDMILL AND TANK.

re the water is pumped into large steel or wooden vats or into low basins (locally called "tanks") excavated in the ground or ned by damming a shallow draw. These tanks are of various s, but ordinarily they have a capacity of several thousand bar- and are very serviceable, since the soil is of such nature that when oughly compact and saturated it permits but little seepage. ical views of windmills and tanks are shown in Pl. XI, *A*, *B*. mill is allowed to operate continuously, and is visited occasionally a rider for purposes of repairs or oiling. Wind is such a con- t factor on the plains that little concern is felt regarding the er to raise the water, and in very few instances are provisions le, or are other means necessary, for lifting it. In a few in- ces gasoline engines are installed for use in case of emergency. he Panhandle a week seldom passes without wind to drive the s so that they will supply sufficient water for the stock.

DEEP-SEATED WATERS.

he project of obtaining artesian water in various parts of the handle, particularly in the red-beds areas at the foot of the High ns, is often considered. In general, the arguments advanced in or of the project are based on the mistaken idea that there is an erground source of supply from the High Plains or the Rocky ntains.

rom what has been stated already it will be understood that the er supply of the High Plains is derived wholly from the rainfall, while the part which sinks into the ground and is added to the nd water may amount to 5 or 6 inches a year, the geologic struc- is not favorable for artesian conditions. Between the Tertiary the underlying red beds there is everywhere a pronounced uncon- nity, and the rocks of the red beds beneath this unconformity are posed chiefly of impervious clays and shales, through which the er can not pass readily. These conditions, then, preclude the bability of artesian water supply having its source on the High ns.

hat the Rocky Mountains are a source for an artesian supply ugh the red beds is also improbable. These red beds, which are red by the Tertiary of the High Plains, reappear in New Mexico nd the western escarpment of the plains, and are exposed along eastern base of the mountains at a higher altitude than in the on east of the plains escarpment. Some of these beds are coarse- ned, and doubtless they contain water in some places, but whether could be reached by deep wells and would yield water in the handle region remains to be determined. Their general relations shown in Pl. II and fig. 3. In the eastern part of the Panhandle

these beds must be very deep seated, probably more than 2,000 fe and the drill has never reached this depth in the red beds anywh in this part of the plains. The only place where the red beds h been well explored is along their eastern margin in eastern Oklahon where, however, artesian water was not found.

At Childress, Tex., 20 miles south of the southeastern corner of t region discussed, the Fort Worth and Denver City Railroad l drilled a well to a depth of 1,300 feet in search of water for engi and shops. From the surface to the bottom of the well the dr passed through nothing but red clay shales containing a few ledg of sandstone and gypsum. Several horizons of salt water were e countered, but no fresh water was obtained.

At a number of points in Oklahoma wells have been drilled search of coal, oil, gas, and water, but so far artesian supplies ha never been found. At Fort Reno the Government sunk a well to t depth of 1,400 feet in search of water for the post, but none v secured. Near Oklahoma City a well 2,050 feet deep passed out the red beds at 1,550 feet. No artesian water was found.

From all data at hand the conclusion must be drawn that chances are very poor for finding artesian water in the red beds un the plains. The red beds present difficulties to very deep drill which usually have been insurmountable, and if artesian water d exist in the lower members of this series it is doubtful if it can reached at a cost which would be generally profitable. However is to be hoped that at some time the experiment will be tried of te ing all of the red-bed strata.

SPRINGS.

There are in the region under discussion two general classes springs—those from the red beds and those from the Tertiary a sand hills. Both in amount of flow and in character of water th springs differ considerably, and for that reason it is thought best describe the two classes separately.

RED-BEDS SPRINGS.

Springs in the red beds are of infrequent occurrence, and th present are rarely strong. They may be classified, according to character of their water, as salt springs, gypsum springs, and fre water springs.

Salt springs.—Along the branches of Red River, Prairie D Salt, and Elm forks, there are a number of weak salt-water sprin often little more than seeps. The horizon from which the water con is usually near the base of the Greer formation. On Elm Fork of R River in western Greer County, Okla., 5 miles east of the Texas li

there are two salt plains of considerable size, fed by a number of strong salt springs, the combined flow of which approximates hundreds of thousands of gallons of salt water a day. No springs as strong as these are found in any part of the Panhandle. Some salt springs occur, however, but so far as known the salt brine of Texas springs is not used, and it is not probable that the salt water of the Panhandle will ever be utilized, on account of the much larger amounts near at hand in Oklahoma.

Gypsum springs.—Practically all the gypsum springs in the Panhandle issue either from beneath or in close proximity to the massive gypsum ledges that make up a considerable part of the Greer formation. Such springs occur along Elm Fork of Red River in Collingsworth County and on the branches of Prairie Dog Fork in Collingsworth, Donley, and Armstrong counties. Sometimes these springs are mere wet-weather seeps, but in a number of cases they are strong, boiling, perennial springs derived from underground streams, flowing from beneath ledges of white gypsum.

Fresh-water springs.—The greater number of the fresh-water springs of the red beds issue from the Quartermaster formation, which, as has been stated, consists largely of sandstone and sandy shale, with but little gypsum or other mineral salts. The conditions are ideal for springs, provided there is a source of supply, and in a region of greater rainfall a large number might be expected to exist. In the Panhandle, however, the number is small. In the Quartermaster formation there are very few bold flowing springs. This is due to the peculiar lithologic character of the rocks, mostly soft sandstones and sandy clays, which, as stated on page 21, usually weather into peculiar rounded knobs and buttresses and into narrow canyons. It is in the latter that the springs occur, and it is not uncommon to find at the head of a little canyon an outcropping ledge of sandstone, beneath which the water seeps out of the bank. The flow is rarely strong, but it is often very persistent, and the water usually accumulates to form a tiny rill in the bottom of the canyon. Ranchmen and farmers frequently take advantage of the soft rock to hollow out a small basin, in which the water collects, often in quantities sufficient to supply a farmhouse, or even to furnish water for a number of cattle.

Springs are occasionally found in the Dockum beds, issuing from beneath ledges of sandstone or from under the conglomerate members. These springs are usually weak and unimportant and so far as noticed not utilized. This latter fact may be attributed chiefly to their inaccessibility, for the Dockum is exposed only along the steep escarpment at the foot of the High Plains.

TERTIARY SPRINGS.

Throughout the High Plains region the Tertiary deposits yield numerous springs, which are always of good water and have long been most advantageous to the settlers and travelers. Camps, forts, farms, and even cities have been located with reference to the proximity of a Tertiary spring or spring-fed creek. In the Texas Panhandle there are thousands of such springs. They are found, usually in great numbers, in every one of the twelve counties described in this report.

The source of supply of the Tertiary springs is chiefly in the ground water, otherwise called the "sheet water," or "underflow," of the High Plains, and they are usually found where deep canyons have been cut into the highlands.

Not infrequently springs occur at the line of contact between the Tertiary deposits and the clay strata of the upper part of the red beds. This condition is due to the ready seepage of water through the Tertiary sands to the top of the impervious red beds, where it flows laterally until it reaches the surface. Many of these contact springs do not issue from a single opening, but the water finds its escape along a zone of seepage extending sometimes for hundreds of yards along the side of a cliff. In such cases the amount of water discharged at any one place is not large, but the aggregate is often considerable.

Excellent springs frequently occur in the sand hills at the contact of the sand and the relatively impervious underlying strata. The flow from these sand-hill springs is seldom strong, but the water is pure and wholesome. Springs of this type occur chiefly in the sand-hill regions of the four eastern counties.

In a region where the underground supply is scanty the water that issues from springs is necessarily limited in amount. Very few of the springs discharge half a second-foot of water, and perhaps the greater number of them will not average one-tenth of that amount. The water usually flows but a short distance and then disappears in the sand. Where there are a number of strong springs in a locality the water unites to form a small creek, which is sometimes perennial, but usually intermittent.

STREAMS.

CLASSIFICATION OF DRAINAGE.

The drainage of this region flows into Mississippi River. The water from the northern part of the area flows into either the Canadian or the North Fork of the Canadian, tributaries of Arkansas River, while the water from the southern part reaches Red River. The drainage may be classified as follows:

North Fork of Canadian drainage.—Coldwater, Palo Duro, and Wolf creeks are tributary to North Fork of Canadian River.

Canadian drainage.—Canadian River flows northeast across this region into Oklahoma, traversing Hutchinson, Roberts, and Hemphill counties. It receives as tributaries a number of small creeks which rise on the plains both north and south of the river, cutting their way through the escarpment and entering the river nearly at right angles. The width of the basin from watershed to watershed averages not more than 35 miles.

Red River drainage.—Five main branches of Red River either rise in or pass through this part of the Panhandle. Beginning on the north they are as follows: (1) Washita River, which in Oklahoma and Indian Territory becomes a stream of considerable size, rises in southwestern Hemphill County and flows east; (2) North Fork has its source in Gray County and flows east across Wheeler County into Oklahoma; (3) Elm Fork has its origin in northwestern Collingsworth County and flows southeast; (4) Salt Fork rises in northern Armstrong County and flows east across Collingsworth County before reaching Oklahoma; (5) Prairie Dog Fork rises on the High Plains far to the west, and in this region flows through Palo Duro Canyon across the southwest corner of Armstrong County. These four branches, North, Elm, Salt, and Prairie Dog forks join at the southeast corner of Greer County, Okla., forming Red River, a tributary of Mississippi River.

STREAMS IN DETAIL.

Coldwater Creek.—In its upper course this stream is known as Rabbit Ear Creek, from the fact that it rises near the Rabbit Ear Mountains, two volcanic peaks in northeastern New Mexico. It flows southeast across Dallam and Sherman counties, then turning northeast crosses the northwest corner of Hansford County, passes into Beaver County, Okla., and empties into Beaver Creek at the town of Hardesty. In its course through Hansford County it has cut a canyon 1 to 3 miles wide and approximately 100 feet deep into the Tertiary rocks of the High Plains. The stream is fed by Tertiary springs. Consequently its water is fresh.

Palo Duro Creek.—This stream flows diagonally across Hansford County from southwest to northeast. It is a typical High Plains stream. Rising on the level prairie, it soon begins to cut a trench, which becomes deeper and wider until in Hansford County it is a canyon 1 to 3 miles wide and 100 feet below the level of the plains. Only in parts of its course is there water the year around. At Hansford, the county seat, the stream is dry except after heavy rains, but

15 miles downstream running water appears. This stream also empties into Beaver Creek in Beaver County, Okla.

Wolf Creek.—Wolf Creek rises on the High Plains a few miles southwest of Ochiltree, the county seat of Ochiltree County, and flows east across Ochiltree and Lipscomb counties into Woodward County, Okla. At old Fort Supply it joins Beaver Creek, forming North Fork of Canadian River. In its upper course it has cut a narrow canyon with precipitous bluffs. Farther down it passes out of the High Plains and enters the sand-hills region, where the bed is wide and sandy. The creek is fed by small branches—Camp, Willow, Cottonwood, Plum, Mammoth, and others—the water of which comes from Tertiary springs among the sand hills. Wolf Creek has the reputation among the cattlemen of being the most constant stream in the Panhandle.

Canadian River.—The largest stream in the Panhandle of Texas, Canadian River, has its headwaters among the high peaks of the Rocky Mountains in northern New Mexico. In its upper course it receives a number of tributaries which are fed by mountain springs. After leaving the mountains it flows southeast first across a plain composed of upper Cretaceous rocks, then for nearly 100 miles through a canyon 500 to 800 feet deep in the Dakota sandstone, finally reaching the red-beds plain in the region north of Tucumcari, N. Mex. At this point it changes its direction to the northeast and so flows out of New Mexico and across the Panhandle of Texas into Oklahoma, where it again turns southeast, finally joining Arkansas River in the eastern part of Indian Territory. Of the 700 miles of its course only about 100 miles are included in the part of the Panhandle under discussion. Across this region it flows in a broad curve, convex to the north, crossing southeastern Hutchinson, northern Roberts, and middle Hemphill counties before passing into Oklahoma. Throughout this distance the river has cut a broad canyon in the High Plains. In places the headlands between the tributary creeks approach almost to the river, but at most points the flood plain, usually a sandy flat, is 2 to 4 miles wide. The channel of the river itself is a sand bed averaging three-quarters of a mile in width.

Canadian River is perhaps more treacherous than any other stream of the plains. The stream is either dry or a raging torrent. The river may have been dry for weeks at a time, when suddenly without warning, a wall of water several feet high rushes down the channel, sweeping everything before it, and for a number of days the river continues high, then gradually subsides. following this period of abnormal flow the sand in the stream becomes "quicksand," or loose sand which appears firm but gives way suddenly under foot rendering the stream extremely dangerous to cross. Many a herd of

A

B

FRESHET ON RED DEER CREEK AT MIAMI, TEX.

cattle has been mired in Canadian River, and every year loaded wagons and even teams are abandoned. The cause of the sudden and rapid rises is not yet fully understood, but most of them are caused by heavy rains near the head of the stream.

Such sudden rises are not confined to the Canadian River, or to the larger streams, for the small streams exhibt the same phenomena, though on a much diminished scale. Pl. XII, *A*, *B*, shows a rise which occurred on Red Deer Creek, a tributary of the Canadian, at Miami, Roberts County, August 16, 1904. The town lies in a rather narrow valley cut by the stream into the High Plains. There had been no rain at Miami for several weeks and the bed of the creek was a dry sand flat. A heavy rain occurred at the head of the creek a few miles southwest, and two hours later the water came down the stream channel, a narrow tongue of white foam, as shown in Pl. XII, *A*. This was followed by a wall of turbid, yellow water that filled the banks of the stream. In half an hour the flood was at its highest, a seething, foam-capped torrent. By next morning the water had disappeared except from a few pools in the channel, as shown in Pl. XII, *B*, and by noon even these were dry.

Canadian River does not receive any large tributaries in its course across the plains. In three counties which it crosses in the region to which this report relates there are a number of small creeks, none more than 25 miles long, emptying into the river. Of these the most important are Spring, Kit Carson, Dixon, Antelope, Blue Bear, Walnut, Buffalo, White Deer, and Red Deer, all of which rise on the High Plains and cut their way through the escarpment before reaching the river.

Washita River.—Only the upper course of Washita River is in Texas, where it is a small creek, not differing from scores of others which take their rise in the escarpment and sand-hill regions. It flows east across the southern part of Hemphill County. Farther east in Oklahoma the valley of the Washita lies almost entirely in the red beds, and it is there known as the muddiest stream of the plains. In Hemphill County, Tex., however, it has not yet cut through the Tertiary, and is here a clear, fresh-water stream.

North Fork of Red River.—This, the northernmost of the four branches which make up the Red River, rises on the High Plains, in Carson County, breaks through the escarpment in Gray County, and flows northeast into Wheeler County, then southeast into Oklahoma. East of the Gray-Wheeler county line the stream has cut through the Tertiary deposits and into red beds, which are here exposed along its north bank, while on the south side sand hills occur. Across Gray and Wheeler counties the bed of North Fork is sand choked and has

a surface flow only part of the year. The chief tributaries of North Fork are McClellan Creek, which drains southern Gray County, emptying near the Wheeler County line, and Sweetwater Creek, which drains northern Wheeler County and passes into Oklahoma before joining the main stream. All of these streams are fed by Tertiary springs, and even where the surface sand is dry water may usually be obtained by digging a few feet.

Elm Fork of Red River.—Northern Collingsworth and southern Wheeler counties are drained by Elm Fork, which rises along the escarpment, but soon reaches the red beds, across which it flows for the greater part of its course in Texas. The water of the upper branches is derived from the Tertiary springs in the sand hills along the escarpment, but as soon as the river enters the red-beds formations, gypsum and salt water flow into it, until by the time it reaches the Oklahoma line the water has lost its purity. Shortly after entering Greer County it receives water from a number of salt springs, and from that point is considered to contain the saltiest water of any stream of the plains.

Salt Fork of Red River.—Salt Fork is a typical stream of the plains. It rises far out on the Llano Estacado in southern Carson County, crosses northeastern Armstrong County, and flows entirely across Donley and Collingsworth counties before reaching the Oklahoma line. In its upper course it is but a shallow draw in the level prairie, but eastward it soon flows in a trench, and 10 miles from its source this deepens into a canyon with cliffs of white Tertiary beds. Up to this point the stream receives no water except the run-off, but a few miles lower in its course it reaches the Tertiary springs level and has a surface flow the greater part of the year. Eastward the bed widens and becomes sand choked, until in central Donley County, north of Clarendon, it cuts through the lower members of the Tertiary and enters the red beds. From that point almost to Mangum, in Greer County, Okla., it flows between red-beds bluffs on the north side and sand hills on the south side. It is a sandy, treacherous stream, dangerous to cross except when low.

Prairie Dog Fork of Red River.—This stream flows southwestward across Armstrong County in Palo Duro Canyon, which has been discussed under "Topography," page 12. This canyon is perhaps the most notable canyon in the High Plains. Near its mouth the walls are approximately 1,000 feet high, composed of red beds in the lower part and of Tertiary deposits above. Several creeks are tributary to this stream, the chief of which, Spillers and Mulberry creeks, drain parts of southern Collingsworth and Donley counties. These streams do not differ materially from others in this region. Spillers Creek rises in the sand hills of Collingsworth County and flows southeast across the red beds into Childress County

A. BUFFALO WALLOW.

B. LAKE ON HIGH PLAINS.

before joining Prairie Dog Fork. Mulberry Creek rises on the High Plains and has cut a deep canyon entirely through the Tertiary to a depth of several hundred feet into the red beds.

DRAINAGE OF THE HIGH PLAINS.

From what has been said it will be understood that there is a considerable portion of the Panhandle which has no developed drainage; in other words, from a great part of the High Plains there is no run-off. The headwaters of the various small streams tributary to Canadian or Red rivers have cut into the slope of the escarpment, but so far, except in a few isolated localities, the flat upland has not yet been invaded and remains still uneroded. It is graphically described by Johnson,[a] who says the plains are the remnants of an old débris apron, unscored by drainage, yet standing in relief.

Scattered at irregular intervals on this flat surface are saucer-shaped depressions, in which water collects. In size these depressions vary from the ordinary "buffalo wallow," a few feet across (Pl. XIII, *A*), to lakes hundreds of rods in diameter (Pl. XIII, *B*). In a few instances, particularly in localities near the edge of the plain, the basins are deep and bowl shaped, as shown on Pl. XIV, *B*. Often the lakes are perennial and afford an abundant supply of stock water the year round; others are ephemeral, being filled by rains but soon becoming dry, while still others contain water part of the year. These lakes occur with no regularity. In some localities on the High Plains there are none of these basins for miles, while in other sections there are scores of them in a single township. Pl. XV represents the conditions on the High Plains in parts of Carson and Gray counties.

Many of the larger depressions have extensive drainage basins, which sometimes collect the water from a number of square miles. Small prairie streams receive the run-off from the outer part of the basin and lead to the lake. It is not infrequent in traversing the High Plains to encounter a sag in the surface along which storm water is carried to a near-by lake. These small stream beds, however, rarely exceed a mile or two in length. In view of the admirable treatment of the subject by Johnson,[b] there seems no need to enter upon a discussion of the origin of these lakes. The writer agrees that the "innumerable hollows in the High Plains surface, large and small alike, are due to ground settlement rather than to some process either of original construction or of subsequent erosion."[c]

The influence of these lakes upon the settlement of the country has been important, for on the High Plains the matter of water supply is

[a] Johnson, W. D., The High Plains and their utilization: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 4, 1901, p. 626.
[b] Ibid., pp. 695–711.
[c] Ibid., p. 702.

vital. In the early history of the Panhandle, before wells had been sunk, these lakes constituted the only source of supply, and thus it happened that the early cow camps were located beside some permanent body of water. In a number of instances a town grew up at the site of the cow camp, and to-day some of the largest county seats—for example, Clarendon, Claude, and Panhandle—owe their location to the presence of such basins. Although windmills are now used to draw water for household use, as shown in Pl. XI, *A*, *B*, a great part of the stock water still comes from the lakes.

IRRIGATION.

NEED OF IRRIGATION.

The Panhandle of Texas is located in the semiarid belt of the Great Plains. The annual rainfall averages approximately 20 inches, but the greater part of this amount is from dashing rains. During certain seasons there is little or no rain. The soil is extremely fertile, and if water were present it is capable of producing abundant crops. At various times on the High Plains farming has been attempted, and often with success for a few years, but usually seasons of drought have ensued and the effort has been abandoned. In general, practically all the crops that have been raised successfully on the High Plains are such forage plants as kaffir corn, sorghum, and milo maize, which are able to mature with a minimum of moisture. At the foot of the plains, particularly along some of the stream valleys, the culture of corn, oats, cotton, and alfalfa is now being attempted with considerable success. Crops are frequently abundant for several successive years, but occasionally fail during periods of drought.

It will be readily understood that in a region with climatic conditions such as those in the Panhandle, irrigation is necessary for successful farming. This fact has long been recognized and a number of desultory attempts have been made to irrigate small tracts but nothing approaching a large system has ever been projected.

POSSIBLE METHODS OF IRRIGATION.

It is proposed in the following pages to discuss four possible modes of irrigation which might be put into operation in the Panhandle of Texas, viz, (1) irrigation from streams, (2) springs, (3) storm water, and (4) wells.

Irrigation from streams.—It has been shown above that the larger streams of this region practically all flow in broad, shifting, sand choked channels, contained between low, sandy banks, and that the water varies constantly, the stream being at one time a rushing torrent, at another nothing but a dry sand bed. Only one of these rivers—the Canadian—has its headwaters in the mountains; all the

others take their rise on the High Plains and are fed by local rains or by springs.

There are no Government gaging stations in the Panhandle of Texas, and no accurate data are available regarding the amount of flow in the various rivers. It is known, however, that enough water passes down the streams each year, particularly during times of flood, to irrigate considerable areas of valuable land. In most cases, however, there would be great difficulty in storing these flood waters. In the first place, so far as known, there are no available dam sites along the larger streams. The broad, shallow channel, sometimes filled to a depth of 100 feet with fine sand, precludes the construction of masonry dams. Besides this, in most cases material for dams is rare, or, indeed, entirely wanting. There are few hard rocks in this region except an occasional local ledge of sandstone or dolomite in the red beds and some indurated Tertiary limestone along the bluffs. Again, the sandy nature of the soil along the streams presents difficulties in the way of the construction of ditches.

Along some of the smaller streams irrigation has been carried on with more or less success. Along Palo Duro Creek, near the post-office of Mulock, in northeastern Hansford County, Robinson Brothers have a plant in operation from which 35 acres are irrigated. The difficulty at this place has been in securing a suitable site for the dam, and the scarcity of material with which to construct it. In former years several dams here have been washed out during times of high water. Other similar plants are projected farther down Palo Duro Creek; one at Range, Okla., 12 miles below Mulock, has been in successful operation for a number of years. In eastern Wheeler County the water of Sweetwater Creek was formerly utilized to irrigate a tract of 60 acres, but in the last few years the project has been abandoned. There are a number of smaller streams where small plants sufficient to irrigate 10 to 25 acres might be successfully installed. Particularly are there opportunities for such projects along Mammoth, Wolf, and Sweetwater creeks, the upper branches of the various forks of Red River, and some of the short tributaries of Canadian River.

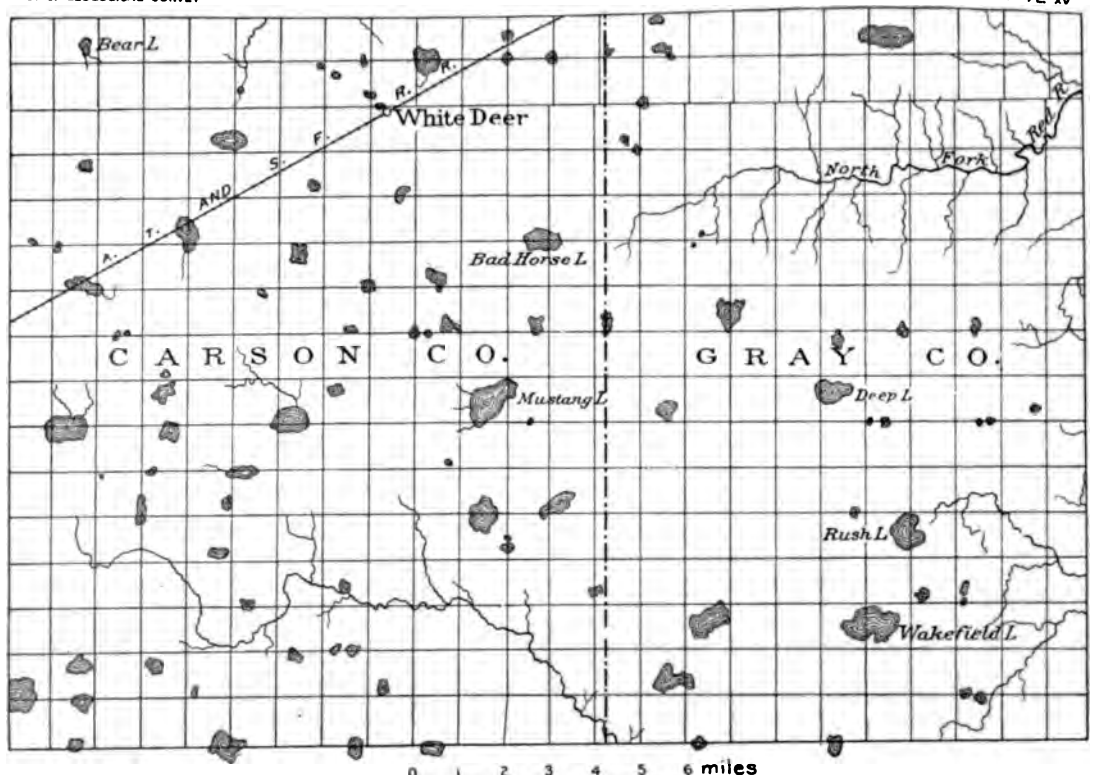
Irrigation from springs.—Since only springs that have a considerable flow can be utilized for this purpose, irrigation from springs must, at best, be confined to limited areas. In the Panhandle it is rather an unusual occurrence for a spring to be located where the water may be led off to irrigate a tract of land, but in a few cases there are springs which are so located that they might be thus utilized. So far as known there is no irrigation directly from a single spring in this region, but there are localities in which a small creek, formed by a number of springs uniting, might be deflected from its channel and carried by a ditch over a tract of land. Examples of

this condition might be cited along the smaller tributaries of W and Sweetwater creeks and Canadian River.

Irrigation from storm waters.—Much of the rainfall of the Pa handle occurs as dashing showers at irregular intervals, chiefly du ing the spring and summer months. After a shower the water the High Plains accumulates in shallow sags which empty into broa shallow "lakes;" while among the breaks and at the foot of t plains it passes into the streams. In numerous places the sags on t High Plains or the dry channels among the breaks have been damme forming reservoirs, known locally as "tanks," to hold stock wat and in a few instances a ditch has been led out from one of the artificial ponds to irrigate a few square rods of garden or orchar While it is obvious that irrigation of this character can never practiced on a large scale, it is nevertheless possible for hundreds families in the region to be provided with home-grown vegetabl and fruit by irrigation from storm waters.

Irrigation from wells.—In the discussion of the subject of ar sian water in another part of this report, the conclusion was reach that the probabilities for artesian supply in the Panhandle are n good. On the other hand, however, ordinary wells, which are co mon in all parts of the region, usually supply considerable amour of water, often more than is needed for stock water and domestic u and the surplus might well be used for irrigation. The chief dif culty in the way of the utilization of well water for these purposes the matter of expense in lifting the water to the surface. In th region wind power is almost universally used for this purpose. localities where wells are shallow, as, for instance, along stream valle or among the sand hills, it has been found profitable to use water fro wells for irrigating areas of considerable size. In the greater pa of the Panhandle, however, the water is too deep to be used in th way. As has been stated, the average depth of the wells on the Hi Plains is over 200 feet, while on the eroded plains the wells avera nearly 100 feet in depth. It is obvious that under such conditio little more can be done than to irrigate a garden or an orchard, a so far as has been observed this is all that is ever attempted. I XIV, A, page 46, shows an orchard and garden at Claude, which irrigated from a well over 250 feet deep. Examples similar to th are not uncommon.

In the sand-hill regions, where the water is not so deep, there are number of instances of small plots irrigated with water obtain from a well. On the red-beds plain there is less irrigation by th means, partly because the gypsum water is not suitable for irrigatio but chiefly because the need of irrigation is not realized.



MAP SHOWING LOCATION OF LAKES ON A PORTION OF THE HIGH PLAINS.

FUTURE OF IRRIGATION.

Taking into account the local facts it seems very doubtful if there will ever be any extensive irrigation in the region under discussion. The supply of water is not sufficient for this purpose except along the larger streams, where the conditions are such that dams can not be constructed. Small streams, springs, artificial ponds, and wells supply water for limited irrigation, sufficient often to raise vegetables and fruit for a family, but not more. As time goes on and the region is more thickly settled, these small plants will increase in number. There is little to warrant the hope that the water supply in the Panhandle will ever increase, and unless some more efficient means than the ordinary windmill be secured to lift the water from deep wells to the surface it is extremely improbable that anything like extensive works can ever be installed. On the other hand, it is obvious that only a very small part of the available water is now being utilized. It is possible that the future will witness in this region thousands of small pumping plants, each capable of supplying sufficient water to irrigate a garden and an orchard.

WATER CONDITIONS BY COUNTIES.[a]

LIPSCOMB COUNTY.

Topography.—Lipscomb County is in the northeastern corner of the Panhandle. Its surface is a level plain trenched from west to east through the middle by the valley of Wolf Creek. This valley is like a great sloping groove, 250 feet below the level of the High Plains at the west line of the county and 500 feet below at the east line. The High Plain along the northern line of the county is being cut into by branches of Beaver Creek. Wolf Creek Valley separates the county into two areas of plains, one forming the table-land between Wolf Creek and Beaver Creek drainage basins, the other lying between Wolf Creek and Canadian River. Sand hills are present in the northeastern part of the county and between Wolf Creek and the southern line.

Geology.—The rocks of the surface in Lipscomb County are en-

[a] There are no Federal public lands in Texas. This State, when it came into the Union by annexation, retained its public lands, and the general system of township and range lines, by which the lands of the greater part of the United States are surveyed, is not employed. No regular section lines exist, but various-sized tracts are laid off, usually in blocks of square miles as they were selected by the land-grant railroads or purchased by individuals. Some of the earliest surveys employed the Spanish vara, which equals 33.385 inches (1,897.7 + varas equal 1 mile). With such a system of survey the roads are irregularly distributed, no correction lines exist, and the location of points by township and range is impossible. In the eastern part of the Panhandle, however, the counties are uniformly 30 miles square, each containing 900 square miles, a condition which tends to obviate much of the difficulty otherwise encountered in attempting to map the region.

tirely of Tertiary and Quaternary age. Gray sandstones and clays predominate and form conspicuous bluffs along the larger streams.

Water supply.—The two largest streams in the county are Wolf Creek and its tributary Mammoth Creek. Wolf Creek enters from Ochiltree County near the center of the west line of the county and flows directly east; Mammoth Creek rises in the northwest part of the county and flows southeast, joining Wolf Creek in Oklahoma a few miles east of the State line. These creeks, as well as a number of other smaller tributaries of Wolf Creek, are spring fed, but in their lower courses flow through sand-choked beds. Ordinarily the amount of water is small, flowing but 1 or 2 second-feet, and at places entirely disappearing under the sand. The streams are subject to sudden rises of a few hours' duration, at which time the creeks flow several hundred second-feet. In this county the drainage is so well developed that few lakes exist on the High Plains. Lipscomb has the reputation among cattle men of being the best watered county in the Panhandle. The sand strata, both that of the Tertiary and in the sand-hill regions, furnishes an abundance of good water, issuing in the form of numerous springs, which reach the surface along the streams. Although their flow is seldom large, these springs are constant in volume and usually perennial in their character. The water is pure and wholesome and almost always free from notable amounts of salts. It is these springs which feed the numerous tributaries of Wolf Creek and render the water so abundant in the county.

Wells on the uplands in the county range from 130 to 333 feet in depth, with an average of 150 feet. In the valleys a maximum depth of 50 feet usually secures an abundance of water, but along Wolf Creek and some of the smaller streams many of the best wells are not more than 20 feet deep. Of the well records secured in Lipscomb County, the average depth was 121 feet.

OCHILTREE COUNTY.

Topography.—Ochiltree County is in the northern part of this region, lying almost wholly on the High Plains and having uniform plains topography. Near the center it is trenched by the head branches of Wolf Creek, in a valley which gradually deepens to the east. Some of the small side branches of Canadian River which head in the southern part of this region are actively eroding the plains, forming rugged breaks. A few of the small branches of Beaver Creek, which head in extreme northern Ochiltree County, have caused but little erosion.

Geology.—The rocks are entirely Tertiary and Quaternary, and, with the exception of the regions of the breaks near the streams, the surface is flat. Along the bluffs there are ledges of Tertiary clay and sand.

Water supply.—There are two drainage systems in this county. The eastern portion is drained by Wolf Creek, which has its source in the central part of the county, where it is a small fresh-water stream, fed by perennial springs, and flows through a wide gorge in the Tertiary rocks. Canadian River drains the southern portion, and branches of this stream, which have their origin in Tertiary springs along the breaks, flow south into Roberts County. A few minor branches of Beaver Creek drain the northern part.

The High Plains surface is entirely without drainage, and shallow lakes are abundant and often of relatively large size, sometimes covering 100 acres or more. Ochiltree County has an abundance of good well water, but ordinarily it is found at a considerable depth. In the southern part of the county, near the breaks, the depth to water exceeds 400 feet, while farther north water is obtained in abundance from 150 to 300 feet. In the Wolf Creek Valley the wells are shallow, many of them finding good water at 50 to 100 feet. The average depth of twenty-four wells in Ochiltree County is 245 feet.

HANSFORD COUNTY.

Topography.—Hansford County is in the northwestern part of the region to which this report relates. It includes a portion of the High Plains, trenched by two streams, Palo Duro Creek, which rises in the extreme southwestern portion of the county and passes into Oklahoma near the northeast corner, and Coldwater Creek, also known as Rabbit Ear Creek, which enters the county near the center of the west line and flows across the northwest corner, passing into Beaver County, Okla. The greater portion of the county retains its original plains features, while a lesser part consists of valleys and breaks. The entire county presents a gradual slope to the east. The highest point in this part of the Panhandle is attained in this county, just south of the center, along the west line—an altitude of 3,750 feet.

Geology.—Nearly all of the surface rocks of Hansford County are of Tertiary and Quaternary age. In the extreme northeast corner Palo Duro Creek has cut through the Tertiary and exposes the underlying red beds. Along Coldwater and Palo Duro creeks bluffs of hard Tertiary rocks occur, but for the most part nothing appears on the surface except ledges of soft Tertiary marl exposed along prairie draws.

Water supply.—With the exception of a small portion at the south which drains into Canadian River, all the waters of this county find their way into the Beaver Creek drainage system. Palo Duro Creek is a small stream which rises in the southwestern part of the county, and gradually deepens its valley in its passage northeast until at the county line it has attained a depth of approximately 300 feet below the level of the High Plains. Its numerous lateral

branches receive the drainage from a considerable area, and at times of heavy rains these discharge their waters into a main trunk, which for a short time becomes a torrent. In its central and lower courses there are fertile valleys which afford good farming land, especially adapted to alfalfa culture. Several small irrigation works have been constructed along the lower part of Palo Duro Creek. The difficulty in maintaining these plants is that the dams, built of rough stone uncemented, wash out in times of freshets. Coldwater Creek crosses the northwest corner of the county, entering from Sherman County, Tex., and passing northeast into Beaver County, Okla. It is a small stream flowing through a well-developed gorge. Lakes similar to those in other parts of the region occur upon the High Plains. Hansford County has an abundance of good well water at depths varying on the High Plains from 190 to 300 feet, and rarely does a well fail to encounter an ample supply. In the valleys springs occur, the water from which is like water from the Tertiary beds, pure and wholesome. The average depth of thirteen wells in this county is 235 feet.

HUTCHINSON COUNTY.

Topography.—Hutchinson County lies in the western part of the region to which this report relates. The surface of its northern part is High Plains. The central and southern part is occupied by the canyon of Canadian River and the breaks on either side formed by short tributary creeks.

Geology.—Along Canadian River and along the small streams flowing into it in the central and southwestern part of the county there are extensive exposures of Permian red beds, consisting of red clays and shales with interbedded dolomite and gypsum members. These rocks have been provisionally referred to the Quartermaster formation. The remainder of the county is composed of typical Tertiary and Quaternary deposits, the former being exposed as bluffs along the streams and the latter as sand hills and alluvium.

Water supply.—The entire drainage of this county flows into Canadian River, which crosses the county from southwest to northeast. On the north side there are several small streams, the chief of which are Kit Carson and Coldwater creeks, while from the south flow White Deer, Spring, Bear, Dixon, and Antelope creeks. Thus the greater part of Hutchinson County is well drained. It has an abundance of good water, and, with the exception of some wells in the Canadian Valley and in its tributary creeks, which find their supply in the red beds, the water is wholesome and free from injurious salts. West from Plemons a number of strong springs occur at the line of contact between the red beds and the Tertiary. On the

High Plains water is obtained at depths ranging from 136 to 320 feet, and in the valleys at less than 20 feet. The well records collected show an average depth of 243 feet.

ROBERTS COUNTY.

Topography.—Roberts County lies in the north central part of the region embraced in this report. The surface of the southern portion is High Plains trenched to the east by the gorge of Red Deer Creek. The northern portion is occupied by the valley of Canadian River, with its broad flood plain bordered by a region of breaks on either side. The breaks are so extensively dissected by the smaller stream canyons that the northern portion of Roberts County is one of the most rugged localities in the Panhandle.

Geology.—The surface rocks are mostly of Tertiary age, with the usual sand hills along the streams. In the northwestern portion of the county Canadian River has cut down into the red beds which are exposed in the bluffs along the north bank. Alluvium deposits occur along this river and its tributaries.

Water supply.—The drainage belongs entirely to the Canadian River system. This river flows through a broad flood plain occupied occasionally by low sandy marshes. The waters of a considerable portion of this country reach the river by parallel streams rising in the south central part and flowing north. Few streams enter from the north side, and those which do are short, steep, and intermittent. Red Deer Creek, a tributary of Canadian River, rises in the southern portion of the county and flows northeast into Hemphill County. Ordinarily this stream has no surface flow, but it becomes a raging torrent when there are sudden storms about its head. Tertiary springs occur along the breaks and canyons and supply a number of small creeks. Wells in the High Plains area are 150 to 350 feet deep, and in the valleys water is obtained at from 0 to 20 feet.

HEMPHILL COUNTY.

Topography.—Hemphill County is in the eastern portion of the Panhandle. Its topography is varied, for Washita River rises in the southwestern corner and its northern portion is crossed by Canadian River. These two river systems have removed practically all of the original High Plains level and reduced the region to broad valleys with undulating surfaces between. Along Canadian River is a wide, sandy flood plain, occupied by sand hills in scattered areas. Sand hills also occur in the north, central, and eastern parts of the county.

Geology.—The rocks are chiefly Tertiary deposits, sand hills, and wash. Small areas of red beds are exposed along the Canadian and

Washita rivers in the eastern portion of the county. Along the streams there are bluffs and outliers of white Tertiary rocks, but the greater part of the county consists of rugged breaks and undulating sand hills.

Water supply.—The drainage system is well developed. The water from more than half of this county finds its way into Canadian River through a number of short, swift streams, many of which are perennial, having their source in Tertiary springs. The southern portion of the county is drained by Washita River, a stream which becomes a prominent river in Oklahoma, but is only a small creek in the Panhandle. Its water, being derived from the Tertiary springs, is fresh and free from the injurious salts so common in the large rivers. Springs are not uncommon in this county, and the water obtained from both springs and wells is almost uniformly soft and pure. The depth at which water is found in Hemphill County varies greatly. In the north, south, and southwest the Tertiary beds of the High Plains furnish fresh water at depths ranging from 100 to 333 feet. In the northern sand-hill regions water occurs at depths of 75 to 150 feet. In Canadian and Washita valleys wells are less than 20 feet deep. Records of nineteen wells at various places in this county show an average depth of 94 feet.

WHEELER COUNTY.

Topography.—Wheeler County lies in the eastern part of the Panhandle. The surface is a part of the eroded plains, except small areas in the northwest and southwest. The region is a rolling plain dissected by two principal streams—Sweetwater Creek and North Fork of Red River—with their tributaries. There are extensive sand-hill regions, one of which, 5 to 10 miles in width, and being widest near the center of the county, extends along the south side of Sweetwater Creek almost the entire length of the county. An area of very prominent sand dunes occupies part of the northeastern corner of the county. The hills are mostly low ridges from one-eighth of a mile to 1 mile long and 10 to 20 feet high. Broken ridges and knolls occur everywhere and blow-outs are common. A third sand-hill region is found in the southwestern part of the county, between North Fork and the headwaters of Elm Fork, and a fourth region is in the extreme southeastern part.

Geology.—Red beds belonging to the Greer and Quartermaster formations appear along North Fork of Red River and the branches of Elm Fork in the southern part of the county. Gypsum, dolomite, and red shales of the Greer formation and the red sandy shales and thin sandstones of the Quartermaster formation may be seen in the vicinity of Shamrock, and red bluffs outcrop along the north side of North Fork entirely across the county. The greater part of the

surface rocks, however, consist of sand derived from the Tertiary deposits and of alluvium along the valleys.

Water supply.—The drainage of this county is through three streams, Sweetwater Creek and North Fork and Elm Fork of Red River. The first named, farthest to the north, is a small perennial stream which rises just beyond the limits of the county and in the eastern part was formerly used to some small extent for irrigation. North Fork of Red River crosses this county from west to east a little south of the center. Ordinarily it is a small stream flowing in a sand-choked bed and receives no important tributaries in this county. The waters of this river are highly impregnated with calcium sulphate and sodium chloride. The extreme southern part of the county drains to Elm Fork of Red River. As might be expected in a region of sand hills, there are in Wheeler County a number of fine springs. Six miles southwest of Mobeetie is Anderson's spring, which boils up out of the sand and runs off down a little canyon. It is one of the strongest springs in the Panhandle and flows perhaps 1 second-foot. It is said to be artesian in character and the water if confined will rise 15 feet. Other noted springs in the county are Nasby Spring (which fills a 3-inch pipe), Broncho Spring, and Stanley Spring (both of which have a very strong flow). Well water from the Tertiary and sand hills is obtained through the greater part of the county at depths of 80 to 200 feet. In the red-beds region, in the southern part, wells are not so deep, rarely exceeding 50 feet, and the water is usually not good, containing a considerable percentage of mineral salts. Records of nineteen wells in this county show an average of 71 feet.

GRAY COUNTY.

Topography.—Gray County occupies the south central part of the region here discussed. The surface is a portion of the High Plains cut into by two streams—North Fork of Red River, which flows through a gorge crossing the county from west to east, and McClellan Creek, flowing in a similar gorge from southwest to northeast, joining North Fork near the eastern line of the county. Wide breaks border the gorge of these two principal streams.

Geology.—With the exception of a small area of red beds near the mouth of McCellan Creek along the eastern line, the rocks of Gray County are entirely Tertiary and Quaternary. High white cliffs are exposed along the edges of the High Plains, and along the breaks and streams there are alluvial deposits and sand hills.

Water supply.—The greater part of the drainage is through North Fork of Red River and McClellan Creek. The former stream, which rises in Carson County just west of the Gray County line and flows east, drains only a limited region at the south through a few short

tributaries, none of which are more than 5 miles in length. The southern portion of the county is drained by McClellan Creek, a branch of North Fork, which rises west of the south central part of the county. Springs from the Tertiary and sand hills occur in a number of places along the streams. Many are from small seeps, but several have an estimated flow of 40 gallons per minute. On the plains good water is obtained at depths ranging from 100 to 280 feet. In the valleys depths to water do not exceed 35 feet. Along North Fork in the eastern part of the county a few wells afford gypsum water; otherwise the supply in this county is pure and wholesome. Records of eleven wells show an average depth of 166 feet.

CARSON COUNTY.

Topography.—Carson County lies in the western part of the region. With the exception of Ochiltree County, Carson contains a larger proportion of the High Plains than any other county here described. The northern part is dissected by tributaries of Canadian River and a very small portion of the eastern part is occupied by the headwaters of Salt Fork of Red River. With these exceptions its surface is the uniform level of the High Plains, dotted at intervals by shallow lakes.

Geology.—In the extreme northwestern portion of the county along the canyons of Antelope and Dixon creeks, tributaries of Canadian River, there are exposures of the red beds, consisting of red clays and shales with ledges of gypsum and dolomite. With this minor exception, the rocks are Tertiary and Quaternary. Along the breaks high Tertiary cliffs are present, but the flat, upland Tertiary constitutes the greater part of the rocks of the county.

Water supply.—The drainage of Carson County is into two systems, Canadian River and Red River, between which is a great flat table-land divide. The former stream receives the water from the northern part of the county through a number of creeks—the most important being White Deer, Spring, Dixon, and Antelope—all of which have their rise near the central line of the county and flow north. The headwaters of Salt Fork of Red River occupy a few square miles in the southwestern part of the county. Most of this county, however, has no drainage other than that which finds its way into the shallow lakes on the level upland and disappears by seepage and evaporation.

In the southern part of Carson County the water table seems to be very deep, for while a few wells secure permanent flows at depths of less than 250 feet, many of them are obliged to penetrate 400 to 450 feet for an adequate supply; but water when found is both abundant and pure. Among the breaks and along the creeks in the northern

part of the county the wells range from 50 to 200 feet. Few springs occur, those which are found being near the base of the Tertiary in the northwestern part of the county.

ARMSTRONG COUNTY.

Topography.—Armstrong county is in the southwestern part of the region. It is a level plain cut by three canyons trending southeast. The central and northwestern part of the county has the uniform surface of the High Plains. The northeastern portion is trenched by the upper course of Salt Fork of Red River, which has its source near the center of the north line of the county. Mulberry Creek Canyon crosses the county from northwest to southeast. In the southwestern portion is Palo Duro Canyon, through which flows Prairie Dog Fork of Red River. Twenty-five miles of this gorge, 875 feet deep and 5 miles wide, lies in Armstrong County. The sides of the canyon are frequently precipitous and exhibit typical banded structure so rough that the canyon is passable by wagon only along selected routes.

Geology.—The best geological sections obtainable in the Panhandle are found along Palo Duro Canyon in Armstrong County, where all the formations discussed in this report are exposed. The Greer and Quartermaster formations of the Permian red beds are particularly well exposed in this canyon. The Dockum formation outcrops halfway up the escarpment, and Tertiary clays, sand, and conglomerate lie along the upper part of the bluffs. The level upland in other parts of the county exhibits the ordinary Tertiary and Quaternary rocks.

Water supply.—Northeastern Armstrong County is drained by the headwaters of Salt Fork of Red River, and Mulberry Creek receives the drainage from the central and southeastern parts of the county. Prairie Dog Fork of Red River in Palo Duro Canyon, in the southwestern part, has no large tributaries in the county, and although it flows through a great canyon the stream itself ordinarily has little or no surface flow, but, like other streams of the plains, is subject to rapid rises after heavy rains near its head. The drainage of a large portion of the county is undeveloped, and the shallow lakes which occur at frequent intervals often reach considerable size. Springs are not common, but a few are found at the base of the Tertiary and among the red beds. On the High Plains water is obtained in abundance in wells ranging in depth from 120 to 320 feet. Few wells have been sunk in the red beds, but those that have been dug usually find water of rather poor quality at depths ranging from 20 to 100 feet. Records of eighteen wells in Armstrong County show an average depth of 207 feet.

DONLEY COUNTY.

Topography.—Donley County lies in the southern part of the region. The northern and western portions are level High Plains. On the eroded plains which occupy the eastern and southern parts of the county the surface is rolling and dissected by many streams. Even on the High Plains the streams occupy well-marked courses and have so dissected the surface that only in a few instances is the upland sufficiently level to permit the water to collect in lakes. The western extension of the sand-hill region, which crosses Collingsworth County south of Salt Fork of Red River, finds its terminus in the escarpment at the base of the High Plains in Donley County.

Geology.—Both red beds and Tertiary rocks are exposed in Donley County. The red beds, including both the Greer and Quartermaster formations, outcrop along the streams, particularly along North Fork of Red River in the region northeast of the center of the county and along Mulberry Creek in the southwestern part. Along the latter stream the Dockum beds occur. Tertiary rocks constitute the High Plains in the northern and western parts of the county; while the sand hills derived largely from Tertiary deposits occupy considerable areas in the central and southern portions. Alluvium is found along the stream valleys.

Water supply.—The drainage of the county is through two branches of Red River—Salt Fork, which crosses the county, and several smaller branches of Prairie Dog Fork, which rise in the county and flow south. Salt Fork flows almost due east across the center of the county. It is a small stream with a sand-choked bed and a flow of but a few second-feet, the water being free from disagreeable salts. The southern part of Donley County is drained by the branches of Salt Fork, the chief of which is Mulberry Creek, rising in Armstrong County and flowing across the southwest corner of Donley County. It is an ordinary stream of the plains, with a wide, sand-choked channel and ordinarily little water, but at times of heavy rainfall it assumes the proportions of a river. Springs are found in both the sand-hill regions and among the red beds. On the High Plains and in the escarpment region wells are from 40 to 250 feet deep. In the valleys and lower portions of the county water is obtained at 20 to 165 feet. The Tertiary and sand-hill water is good, while that found in the red beds is usually bad. Records from thirty wells show an average depth of 152 feet.

COLLINGSWORTH COUNTY.

Topography.—Collingsworth County forms the southeastern portion of the region here discussed. This county, which is almost wholly in the eroded plains, presents the most diverse topography of all here described. It is trenched from northwest to southeast by three stream systems—Elm and Salt forks of Red River, and Spillers Creek, a branch of Prairie Dog Fork. Just west of the center and extending entirely across the county, trending slightly west of south, are the Dozier Mounds, composed of hard ledges of sandstone underlain by stratified clays, shales, and sandstones. In the southwestern corner of the county these hills are deeply dissected by streams, rendering the region very rugged. On the south side of Salt Fork is a sand-hill region ranging from 2 to 9 miles in width, extending from northwest to southeast entirely across the county.

Geology.—The greater part of the rocks of Collingsworth County belong to the Greer and Quartermaster formations of the red beds. Along the various streams ledges of gypsum and dolomite outcrop, while at a higher level soft sandstones occur. The extreme northwestern part of the county is in the escarpment region, and Tertiary and Quaternary sand hills appear south of Salt Fork of Red River.

Water supply.—Elm Fork of Red River rises in the northwestern portion of the county and flows southeast, leaving the county 9 miles from the northern limit, thus draining the entire northern portion. Salt Fork of Red River crosses the county from west to east in a tortuous course near its center and drains the middle portion of the county. Spillers Creek, a branch of Prairie Dog Fork of Red River, has its source in Donley County and flows southeast across Collingsworth, draining the southwestern part. Except in the sand-hill regions south of Salt Fork, good water is difficult to obtain for the reason that the county is underlain by red beds, which contain large quantities of gypsum and other mineral salts. There are a number of springs of good water among the sand hills. Springs occur in the red beds also, but the water often contains salt or gypsum and is not suitable for general domestic use. Wells in the sand hills are 10 to 220 feet in depth and in the red beds 40 to 190 feet. Records from twenty wells in Collingsworth County show an average depth of 105 feet.

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WS 101. Underground waters of southern Louisiana, by G. D. Harris, with discussions of their uses for water supplies and for rice irrigation, by M. L. Fuller. 1904. 98 pp., 11 pls.
WS 102. Contributions to the hydrology of eastern United States, 1903, by M. L. Fuller. 1904. 522 pp.
WS 104. Underground waters of Gila Valley, Arizona, by W. T. Lee. 1904. 71 pp., 5 pls.
WS 110. Contributions to the hydrology of eastern United States, 1904; M. L. Fuller, geologist in charge. 1904. 211 pp., 5 pls.
PP 32. Geology and underground water resources of the central Great Plains, by N. H. Darton. 1904. 433 pp., 72 pls.
WS 111. Preliminary report on underground waters of Washington, by Henry Landes. 1904. 85 pp. 1 pl.

WS 112. Underflow tests in the drainage basin of Los Angeles River, by Homer Hamlin. 1904. 55 pp., 7 pls.

WS 114. Underground waters of eastern United States; M. L. Fuller, geologist in charge. 1904. 285 pp., 18 pls.

WS 118. Geology and water resources of east-central Washington, by F. C. Calkins. 1905. 96 pp., 4 pls.

B 252. Preliminary report on the geology and water resources of central Oregon, by I. C. Russell. 1905. 138 pp., 24 pls.

WS 120. Bibliographic review and index of papers relating to underground waters published by the United States Geological Survey, 1879–1904, by M. L. Fuller. 1905. 128 pp.

WS 122. Relation of the law to underground waters, by D. W. Johnson. 1905. 55 pp.

WS 123. Geology and underground water conditions of the Jornada del Muerto, New Mexico, by C. R. Keyes. 1905. 42 pp., 9 pls.

WS 136. Underground waters of the Salt River Valley, by W. T. Lee. 1905. 194 pp., 24 pls.

B 264. Record of deep-well drilling for 1904, by M. L. Fuller, E. F. Lines, and A. C. Veatch. 1905 106 pp.

PP 44. Underground water resources of Long Island, New York, by A. C. Veatch and others. 1905.

WS 137. Development of underground waters in the eastern coastal plain region of southern California, by W. C. Mendenhall. 1905. 140 pp., 7 pls.

WS 138. Development of underground waters in the central coastal plain region of southern California, by W. C. Mendenhall. 1905. 162 pp., 5 pls.

WS 139. Development of underground waters in the western coastal plain region of southern California, by W. C. Mendenhall. 1905. 105 pp., 7 pls.

WS 140. Field measurements of the rate of movement of underground waters, by C. S. Slichter. 1905. 122 pp., 15 pls.

WS 141. Observations on the ground waters of Rio Grande Valley, by C. S. Slichter. 1905. 83 pp., 5 pls.

WS 142. Hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 13 pls.

WS 145. Contributions to the hydrology of eastern United States; M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls.

WS 148. Geology and water resources of Oklahoma, by C. N. Gould. 1905. 178 pp., 22 pls.

WS 149. Preliminary list of deep borings in the United States. Second edition, with additions, by N. H. Darton. 1905. 175 pp.

PP 46. Geology and underground water resources of northern Louisiana and southern Arkansas, by A. C. Veatch. 1906.

WS 153. The underflow in Arkansas Valley in western Kansas, by C. S. Slichter. 1906.

WS 154. The geology and water resources of the eastern portion of the Panhandle of Texas, by C. N. Gould. 1906. 64 pp., 15 pls.

The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Pt. II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Pt. II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Pt. II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Pt. IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Pt. IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Pt. IV; Artesian well prospects in the Atlantic coastal plain region, by N. H. Darton, Bulletin No. 138.

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WASHINGTON, D. C.

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FLUCTUATIONS OF THE WATER LEVEL IN WELLS, WITH SPECIAL REFERENCE TO LONG ISLAND, NEW YORK.

By A. C. Veatch.

INTRODUCTION AND SUMMARY.

In connection with the investigation of the geology of Long Island by the United States Geological Survey in the summer of 1903, a few observations were made on the fluctuation of the water level in wells, both with direct-reading and self-recording gages. In the consideration of these data, as well as those collected at the same time by the New York City commission on additional water supply, it has seemed desirable to enter into a general discussion of the fluctuation of water in wells.

Some of the results of this study may be briefly summarized as follows:

1. The most important and characteristic of the natural ground-water fluctuations is the regular annual period. This is a relatively uniform curve, with a single maximum and minimum, on which the fluctuations of shorter periods, as a rule, form but minor irregularities. This curve does not generally resemble the rainfall curve. Were the rainfall uniform throughout the year, the ground water would still show a regular yearly period and the maximum would occur early in the year in the North Temperate Zone. The effect of irregularities in the rainfall is to move the time of occurrence of this maximum either forward or back.

2. The water from single showers is generally delivered gradually to the ground-water table, and even where noticeable fluctuations are produced, these do not commonly make important irregularities in the regular annual ground-water curve.

3. Single showers may, by transmitted pressure through the soil air, produce instantaneous and noticeable rises in the water in wells and notably increase the stream discharge without contributing either to the ground water or directly to the surface flow.

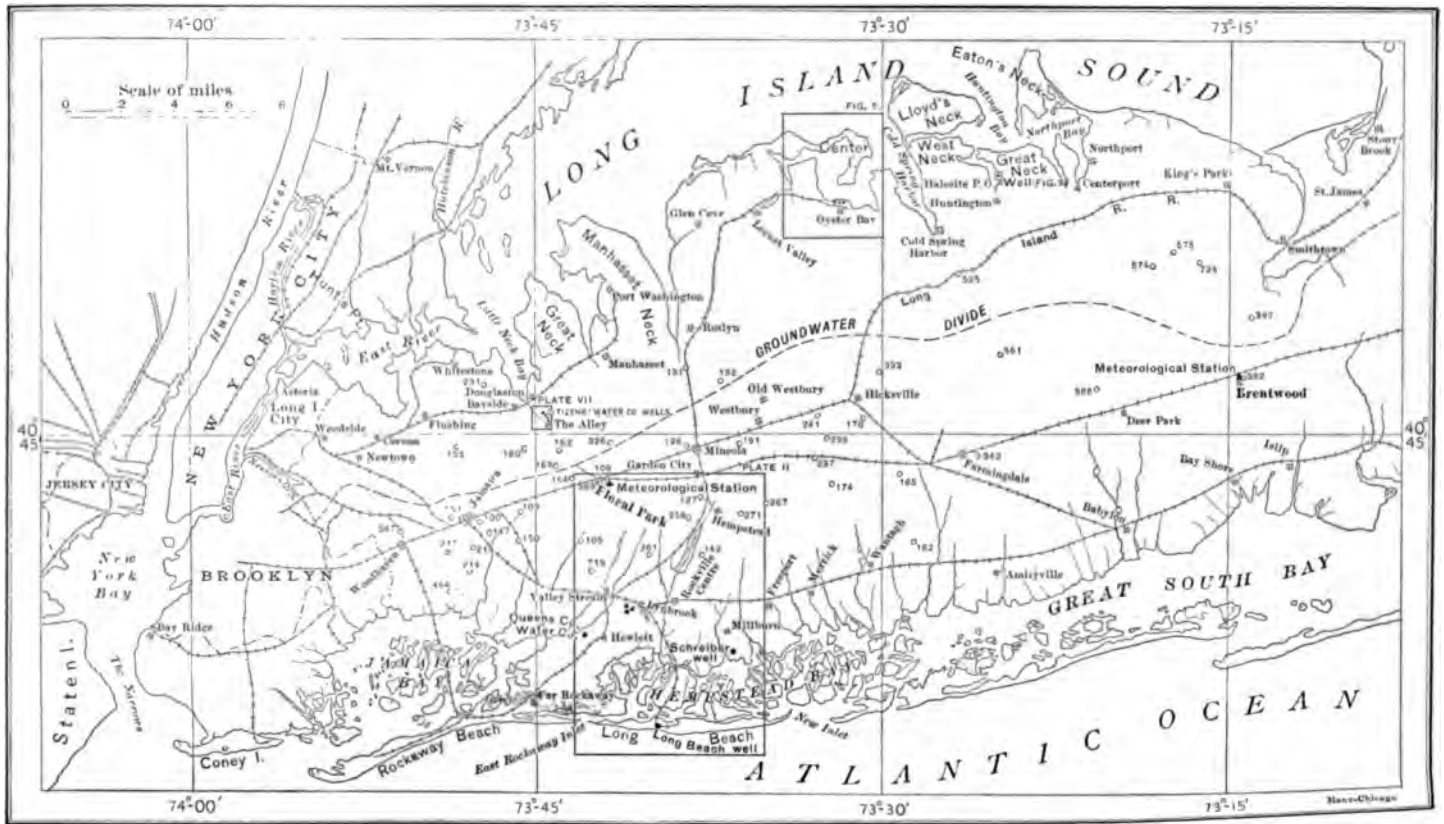
4. The amount contributed to the ground water can not be satisfactorily estimated by the rise and fall of the water in wells, because the same amount of rainfall under the same geologic and climatic conditions, in beds of the same porosity, will produce fluctuations of very different values. Near the ground-water outlet the total yearly range may be but a few inches, while near the ground-water divide it may be 50 or 100 feet. When an attempt is made to calculate the amount of water received from single rains, the results are not reliable, because in the cases which are usually taken, such as sharp, quick rises, it is impossible to tell how much of the rise is due to transmitted pressure and how much to direct infiltration.

5. Because of the increase in stream flow due (1) to transmitted pressure from rains, (2) to changes in barometric pressure, and (3) to increase in area of ground-water discharge, with the elevation of the ground-water table, it is not possible to

correctly separate the quantity of water in the stream discharge contributed by s flow from that contributed by direct surface run-off. There are many reaso believing that in humid regions "flood flows" contain large percentages of g water.

6. Tidal fluctuations in wells are very often produced by a plastic deformatio to the loading of the tides, and the occurrence of such fluctuations in wells do in itself indicate a connection between the water-bearing strata and the sea.

7. Temperature changes may produce marked fluctuations (1) by changes in ca attraction—such fluctuations are perceptible only at the surface of the zone of plete saturation, are not transmitted to deeper levels, and vary directly wit temperature; (2) by changes in viscosity or rate of flow—fluctuations due t cause vary inversely with the temperature, and show in deep wells by transm pressure.



SKETCH MAP OF WESTERN LONG ISLAND, SHOWING LOCATION OF DETAILED MAPS (PLS. II AND VII AND FIGS. 2, 4, AND --, AND POSIT ON OF WELLS REFERRED TO IN FIG. 13.

PART I.

LONG ISLAND OBSERVATIONS.

INTRODUCTORY OUTLINE OF THE HYDROLOGIC CONDITIONS.

The conditions on Long Island, New York, are particularly favorable for the study of the fluctuations of water in wells. The geologic and topographic conditions are such that it may be affirmed that the underground water is derived wholly from the rain which falls on the surface of the island, and the problems involved are, therefore, not unduly complicated, as they are in many regions, by the possibility of the influx of water from other areas. In addition to this comparatively complete ground-water isolation, the island is of such a size—120 miles long and 20 miles wide—that ground-water phenomena can attain a relatively complete development, and the geologic structure of the water-bearing beds, while not complicated, is sufficiently varied to produce several differing conditions.

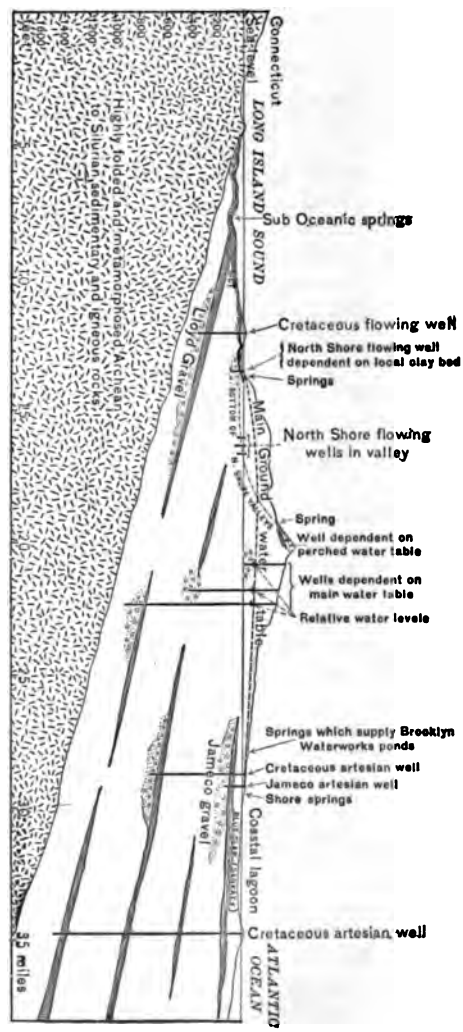


Fig. 1.—Diagrammatic cross section of Long Island, showing principal topographic and geologic factors influencing the underground-water conditions.

Topographically the western part of Long Island—the portion involved directly in this paper—may be said to consist of a single range of rolling hills, usually 150 to 250 feet high, though in one place attaining an elevation of over 400 feet. This hill range descends somewhat abruptly to the north shore, where it is cut by several reentrant bays occupying old valleys. On the south side is a very flat gravel plain, sloping gently to the ocean, along which a series of barrier beaches inclosing long marshes has been developed. To the east the hill range divides and produces two hilly peninsulas, each with a single ridge on the northern side.

Geologically the island may be regarded as a series of relatively porous gravel and sand beds, containing irregular and discontinuous clay masses, the whole limited

below by the peneplained surface of a mass of highly disturbed and metamorphosed Paleozoic and pre-Paleozoic rocks, which have little water value except as a more or less complete barrier to downward percolation (fig. 1). While these unconsolidated beds represent, in the geologic time scale, several of the divisions of the Upper Cretaceous and as many as five Pleistocene or glacial stages, and as a whole are stratified deposits dipping at very low angles south and southeastward, they are, under the island essentially continuous from a water standpoint, and the rain falling on the surface is relatively free to pass to any part of the mass. The Pleistocene beds which form the surface are, however, as a rule, coarse and more porous than the underlying Cretaceous and tend to increase the absorbing power of the island. As a result, the percentage of rainfall which passes into the streams without first going through the ground is extremely small.[a] This percolating water has entirely saturated the porous strata above the bed rock, except a limited portion at the surface, and has driven out the salt water which filled these beds when they were first deposited and which reoccupied them, at least in part, during the several submergences to which the region has been subjected. The surface of this zone of complete saturation, or the main ground-water table, is coincident with the sea level at the shores and becomes more and more elevated in passing inland, though the rate of increase of elevation is less than that of the surface, of which it is but a subdued reflection (fig. 1).[b]

This slope of the ground-water table permits the development of artesian wells at many points on the coast, at elevations which are commonly less than 10 feet above high tide. The head is, in all cases, due to the greater height of the ground water in the adjacent hill mass. In order that such a differential head may be developed, it is merely necessary that the water-bearing bed in question be coarser than the overlying beds. A clay or other impervious cover is not essential and, indeed, is often absent.

OBSERVATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

Observations on the fluctuations of the water level in wells were made by the Geological Survey near Huntington, Oyster Bay, Valley Stream, Millburn, Long Beach and Douglaston, all villages on Long Island west of longitude 73° W., and between latitudes 40° 35′ and 40° 55′ N. (Pl. I.)

OBSERVATIONS WITH DIRECT-READING GAGES.

OBSERVATIONS AT HUNTINGTON, N. Y.

The Huntington observations, from which the other Survey observations developed, were undertaken to test the common report that the discharge of most of the artesian wells along the northern shore of Long Island fluctuated with the tide; in some cases the flow ranging from 0 at low tide to over 100 gallons per minute at high tide. Nearly all of these wells were being pumped, or were utilized to run rams, but permission was obtained to gage a newly completed well belonging to the Huntington Light and Power Company, at Huntington Harbor, until it should be connected with the pumps—a period of three or four days.

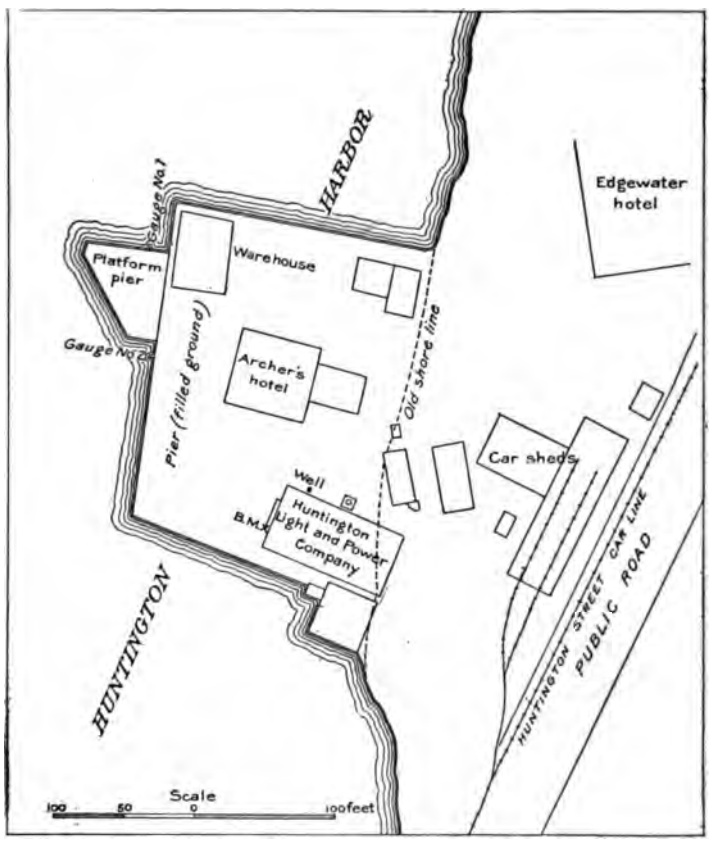
A direct-reading float gage of simple type was quickly constructed by Baker & Fox, Brooklyn, N. Y. This consisted of a 2-inch cylinder of brass carrying a ¼-inch aluminum rod 6 feet long and graduated to hundredths of a foot, with the zero point just

[a] Spear (Rept. New York City Commission on Additional Water Supply, 1904, p. 829) has estimated that 43 per cent of the total stream flow (or 14 per cent of the rainfall) can be considered as flood flow or as not having passed through the ground. He bases this judgment on the relative heights of the stream and ground-water levels near the south shore, where, as explained on page 51, a correct judgment can not be formed. The average flood flow is believed to be much less than 5 per cent of the precipitation.

[b] For details of the slope of the ground-water table see Prof. Paper U. S. Geol. Survey No. 44, 19[illegible], Pls. XI, XII.

ve the cylinder. For convenience in carrying, as well as to avoid the use of so g a rod except where absolutely necessary, the rod was divided into three parts l jointed. The cylinder was so constructed that it would just carry the total length 3 feet, and when used with only 2 or 4 feet of rod, weights, balancing the effect of part removed, were added to the bottom of the cylinder.

ome trouble was experienced by the float tending to approach the side of the well l develop a thin capillary film between it and the pipe, which decreased the sen- veness of the gage. It is suggested that when direct-reading floats are used in ls of small diameter they be kept away from the walls of the well by means of



2.—Sketch map showing location of well of Huntington Light and Power Company at Huntington Harbor, N. Y.

htly arched wires, as in the float devised by Professor King for the self-recording es used in the Madison experiments and later on Long Island.

he well of the Huntington Light and Power Company is situated on a dock at ntington Harbor, near Halesite post-office (Pl. I, fig. 2.) The natural level of the ace at the point where the well is sunk is between high- and low-tide mark, but ground has been built up by filling about 5 feet higher. The well is 75 feet deep 4 inches in diameter, and the water rises in the pipe from 1 to 3 feet above the ace of the made ground. The well was piped above the limit of flow, so that all fluctuations could be measured directly, rather than inferred from variations in rate of discharge.

The geologic section reported by the driller, Mr. H. J. Dubois, is as follows:

Section of well of Huntington Light and Power Company at Huntington Harbor, Halesite, N. Y.

	Feet.
1. Filled ground	0- 6
2. Swamp deposit	6-10
3. Dark sand and gravel	10-70
4. Blue clay	70-71
5. Light-yellow gravel containing artesian fresh water	71-75

The artesian flow is due to the height of the ground water in the steep hill just east of the well, the head being transmitted through the coarse beds encountered in the bottom of the well. Water escapes in many springs along the beach, but the movement through the lower gravels is freer and a differential head is produced,

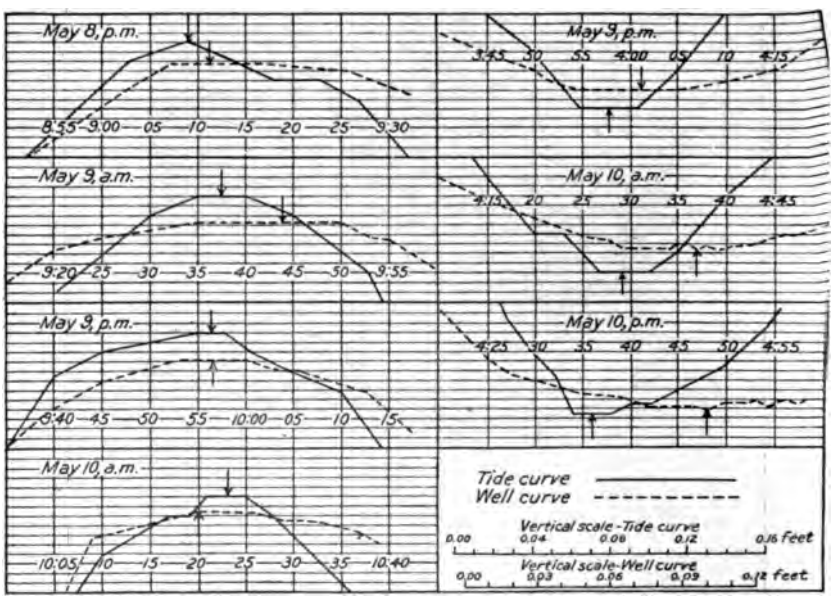


FIG. 3.—Details of well and tide curves at Huntington Harbor, N. Y., showing lag between well and tide. From observations with direct-reading floats by A. C. Veatch and Isaiah Bowman.

which, when a free escape to the surface is afforded, as by a well tube, causes a flowing well. The blue-clay layer reported probably represents the feather-edge of a sheet which thickens under the harbor, but does not extend beyond it. This is inferred from the general geologic relations of the region.

A board gage divided to tenths of a foot was placed on the north side of the platform pier at the point marked "Gage No. 1" in fig. 2. There was relatively still water at this point, and the oldest inhabitant stated positively, when the board was placed, at about 6 p. m. on May 8, that the foot of the gage would not be exposed at low water. Observations were at once begun on the well and tide gage, and continued until 3 o'clock on the morning of May 9, when at low tide the bottom of the gage was exposed. The gage was then moved to point No. 2, south of the platform pier, and the observations continued from 7.38 a. m. May 9 to 7.30 p. m. May 10 and thus four high and three low waters were compared.

bench mark established was as follows: Cross on top of south end of doorsill, ide of building of Huntington Light and Power Company. The elevation the zero of gage No. 2 is 12.232 feet.

observations here gave curves of the same general character as those plotted er Bay (fig. 8, p. 16).

two curves are essentially parallel, and while the semidiurnal range of the tide t 8 feet, that of the well is about 2 feet. The low water in the well is 3.5 feet he highest water in the bay.

g. 3 the high- and low-tide readings for both the well and the tide have been on a large scale, with the same time values, but with different vertical values, r to bring out the amount of time the fluctuations in the well lag behind those ide. These curves indicate that for the period of observation the low tide in ll has an average establishment, or lag behind the ocean waters, of two s and the high tide eight minutes.

Iay 11 Mr. Isaiah Bowman made observations with the direct-reading floats hallow 6-inch flowing well belonging to the Consolidated Ice Company, at igton. It is located about a mile from the harbor, at an elevation of 40 feet. servations were continued for six hours and no fluctuations of any character

OBSERVATIONS AT OYSTER BAY, N. Y.

ng the month following the observations at Huntington Harbor it was found ong the many flowing wells at Oyster Bay four could be observed for a lim-ne.

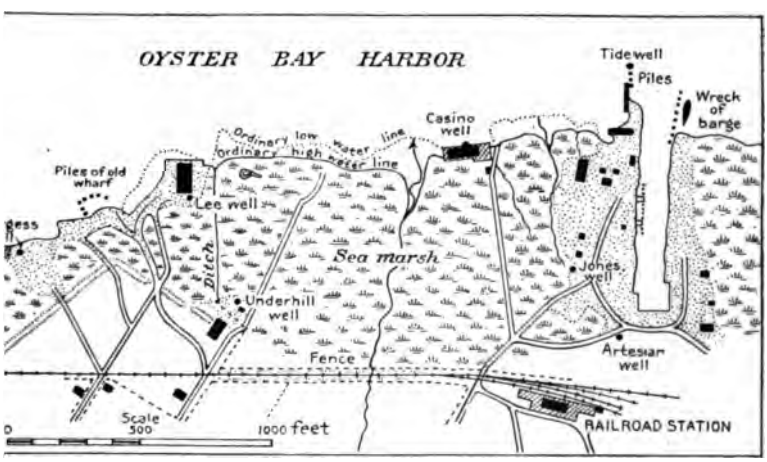


FIG. 4.—Sketch map showing location of wells observed at Oyster Bay, N. Y.

e wells are all very near the shore; indeed, the Casino well, which is beneath or of a building extending over the water, is always covered at high tide (fig. 4). ners, the Burgess, Lee (or Hill), and Underhill wells (fig. 4), are at distances 50 to 500 feet from ordinary high-tide mark, though the ground at all is cov-hen extraordinary wind-aided tides occur. The depths of these wells, as ined by soundings at the time of the observations, were: Casino, 93 feet; ill, 114 feet; Lee, 188 feet; Burgess, 155.5 feet. The Casino and Lee are 3-inch nd the Burgess and Underhill 2-inch wells. All these wells pass through a layer of sand and gravel, then a layer of blue clay 50 to 75 feet thick, and penetrate a rather coarse water-bearing sand. In some cases the upper sands vels will furnish flowing water, but all the wells observed obtain their supply

from below the blue-clay layer (fig. 6). This blue clay thins rapidly southward a entirely disappears half a mile south of the wells (fig. 7). It extends under Oys Bay Harbor and is exposed in the clay pits on the south end of Center Island.[a]

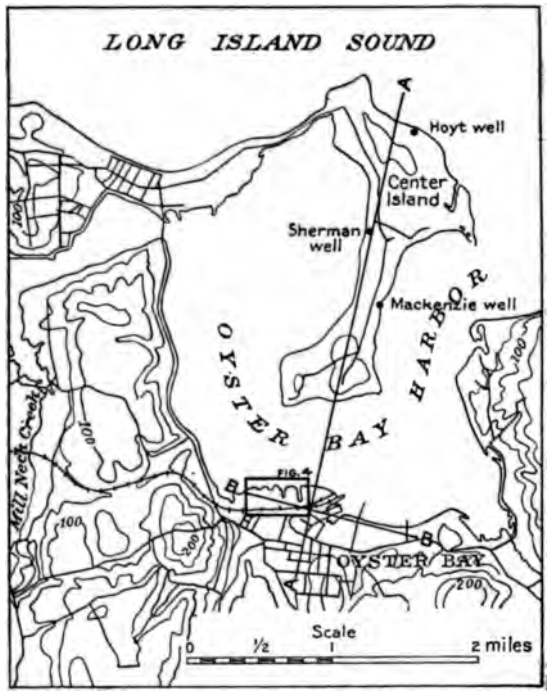


FIG. 5.—Sketch map showing topographic surroundings of wells shown in fig. 4 and location of sections shown in figs. 6 and 7.

All these wells were flowing, and in each case, before observations were commenc lengths of pipe were added until the wells no longer flowed, even at high tide. Fl gages similar to those used at Huntington were then inserted and the wells cove

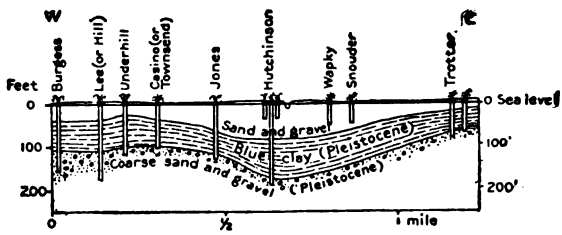


FIG. 6.—Section at Oyster Bay, N. Y., along line B–B, fig. 5, showing geologic relations of wells observed.

with flat-topped caps, each containing a smooth beveled hole through which t gage rod extended.[b]

[a] The folding of the beds here shown is due to ice shove. See Prof. Paper U. S. Geol. Survey No. 1906, pp. 39–43.

[b] The general conditions of observation are well shown in Prof. Paper U. S. Geol. Survey No. 44, P Pl. XIII, *A*. This view indicates, in a very graphic manner, the relation of the wells to the wate the bay and the considerable head developed by these fresh-water artesian wells on the seashore.

der to obtain more refined results than were possible with the board gage a gton, a 3-inch pipe, perforated at a point several feet above the bottom, wa in the harbor at the end of a row of piles and at a distance of about 200 fee

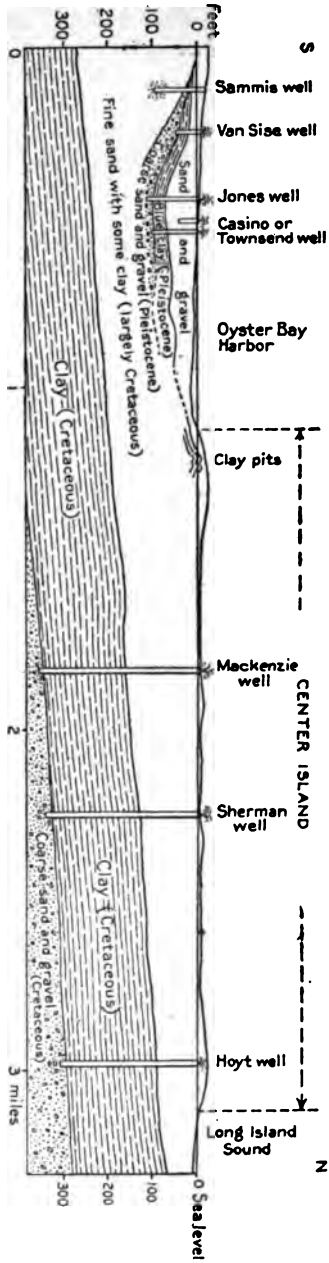


FIG. 7.—Section at Oyster Bay, N. Y., along line A–A, fig. 5, showing geologic relations of the artesian wells at Oyster Bay and on Center Island.

shore (fig. 4). This still box or tide well was fitted with a direct-reading like those used in the artesian wells. This arrangement is not to be rec- d during stormy weather, but fortunately during the whole time of obser- this place no trouble was experienced from that cause.

Observations were commenced on the Casino, Underhill, and Burgess wells on the evening of May 30, by a party in charge of Mr. Isaiah Bowman, and continued, with interruptions on the nights of May 30 and 31 and June 1, to 10 p. m. on June 4.

On June 10 and 11 observations were made on the Lee (or Hill) well, covering two high and two low tides, and for the purpose of comparison the Casino and tide wells were also observed. Observations were generally made every minute for thirty minutes preceding and following the times of high and low water, and from these values the curves shown in fig. 8 were drawn. Times of high and low water were found by plotting the observations near high- and low-tide marks on a much large scale, in the manner shown in fig. 3. The values so obtained are indicated on fig. 8 and are given in the following table:

Difference in time between high- and low-water stages in four artesian wells at Oyster Bay, N. Y., and the tide in Oyster Bay Harbor.

[Time expressed in hours and minutes of 24-hour clock.]

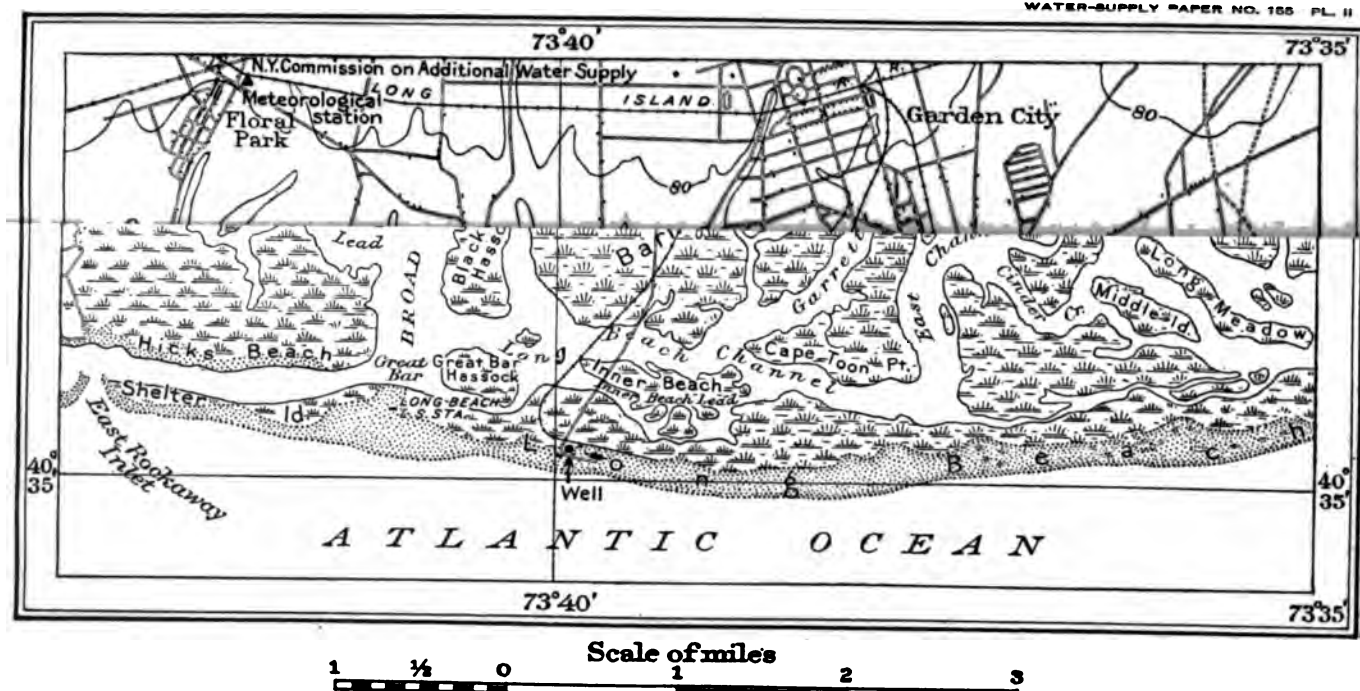
HIGH TIDES.

1903.	May 30.	May 31.		June 1.	June 2.		June 3.		June 4.	June 10.	June 11.	Average lag.
												Minutes.
Casino well	.....	.....	14.52	.....	.....	17.05	5.19	18.11	6.38	.....	12.22	
Tide	.....	.....	14.43	.....	.....	16.54	5.12	18.02	6.29	.....	12.20	
Difference (lag)	.....	.....	.09	.....	.....	.11	.07	.09	.09	.....	.02	0.8
Burgess well	.....	.....	15.13	16.05	.....	17.15	5.38	18.25	6.56	.....	.....	
Tide	.....	.....	14.43	15.44	.....	16.54	5.12	18.02	6.29	.....	.....	
Difference (lag)	.....	.....	.30	.21	.....	.21	.26	.23	.27	.....	.....	24.7
Lee well	.....	.....	.....	.....	.....	.....	.....	.....	.....	a0.20	13.12	
Tide	.....	.....	.....	.....	.....	.....	.....	.....	.....	23.48	12.20	
Difference (lag)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.32	.52	.4
Underhill well	.....	.....	16.02	17.02	.....	18.00	6.20	19.10	7.41	.....	.....	
Tide	.....	.....	14.43	15.44	.....	16.54	5.12	18.02	6.29	.....	.....	
Difference (lag)	.....	.....	1.19	1.18	.....	1.06	1.08	1.08	1.12	.....	.....	71.8

LOW TIDES.

Casino well	20.28	9.21	.....	.....	.....	23.46	12.08	.....	0.47	17.42	6.32	
Tide	20.10	9.04	.....	.....	.....	23.36	11.55	.....	.38	17.33	6.20	
Difference (lag)	.18	.17	.....	.....	.....	.10	.13	.....	.09	.09	.12	12.6
Burgess well	.....	.....	.....	10.41	11.26	a0.10	.....	12.28	1.04	.....	.....	
Tide	.....	.....	.....	10.00	10.53	23.36	.....	11.55	.38	.....	.....	
Difference (lag)	.....	.....	.....	.41	.33	.34	.....	.33	.26	.....	.....	33.4
Lee well	.....	.....	.....	.....	.....	.....	.....	.....	.....	18.23	7.26	
Tide	.....	.....	.....	.....	.....	.....	.....	.....	.....	17.33	6.20	
Difference (lag)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.50	1.06	.5
Underhill well	21.25	10.17	.....	11.22	12.06	a0.55	.....	13.11	1.49	.....	.....	
Tide	20.10	9.04	.....	10.00	10.53	23.36	.....	11.55	.38	.....	.....	
Difference (lag)	1.15	1.13	.....	1.22	1.13	1.19	.....	1.16	1.11	.....	.....	75.6

a Morning of following day.



MAP OF PORTION OF SOUTHERN LONG ISLAND, SHOWING LOCATION OF HEWLETT, LONG BEACH, MILLBURN, AND LYNBROOK WELLS.

Observations were commenced on the Casino, Underhill, and Burgess wells on the evening of May 30, by a party in charge of Mr. Isaiah Bowman, and continued, with interruptions on the nights of May 30 and 31 and June 1, to 10 p. m. on June 4.

On June 10 and 11 observations were made on the Lee (or Hill) well, covering two high and two low tides, and for the purpose of comparison the Casino and tide wells were also observed. Observations were generally made every minute for thirty minutes preceding and following the times of high and low water, and from these values the curves shown in fig. 8 were drawn. Times of high and low water were found by plotting the observations near high- and low-tide marks on a much larger scale, in the manner shown in fig. 3. The values so obtained are indicated on fig. 8, and are given in the following table:

Difference in time between high- and low-water stages in four artesian wells at Oyster Bay, N. Y., and the tide in Oyster Bay Harbor.

[Time expressed in hours and minutes of 24-hour clock.]

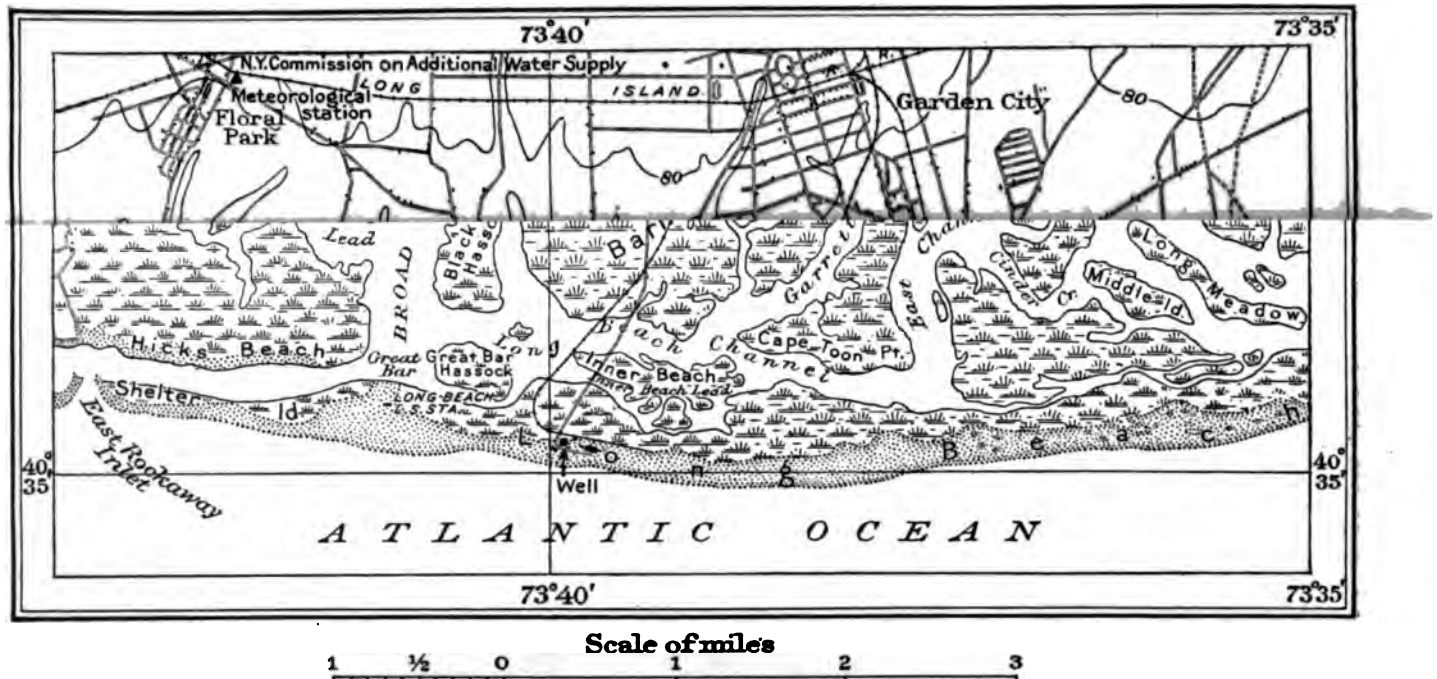
HIGH TIDES.

1903.	May 30.	May 31.		June 1.	June 2.		June 3.		June 4.	June 10.	June 11.	Average lag.
												Minutes.
Casino well	.....	.....	14.52	.....	.....	17.05	5.19	18.11	6.38	.....	12.22	
Tide	.....	.....	14.43	.....	.....	16.54	5.12	18.02	6.29	.....	12.20	
Difference (lag)	.....	.....	.09	.....	.....	.11	.07	.09	.09	.....	.02	0.8
Burgess well	.....	.....	15.13	16.05	.....	17.15	5.38	18.25	6.56	.....	.....	
Tide	.....	.....	14.43	15.44	.....	16.54	5.12	18.02	6.29	.....	.....	
Difference (lag)	.....	.....	.30	.21	.....	.21	.26	.23	.27	.....	.....	24.7
Lee well	.....	.....	.....	.....	.....	.....	.....	.....	.....	a0.20	13.12	
Tide	.....	.....	.....	.....	.....	.....	.....	.....	.....	23.48	12.20	
Difference (lag)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.32	.52	.42
Underhill well	.....	.....	16.02	17.02	.....	18.00	6.20	19.10	7.41	.....	.....	
Tide	.....	.....	14.43	15.44	.....	16.54	5.12	18.02	6.29	.....	.....	
Difference (lag)	.....	.....	1.19	1.18	.....	1.06	1.08	1.08	1.12	.....	.....	71.8

LOW TIDES.

Casino well	20.28	9.21	.....	.....	.....	23.46	12.08	.....	0.47	17.42	6.32	
Tide	20.10	9.04	.....	.....	.....	23.36	11.55	.....	.38	17.33	6.20	
Difference (lag)	.18	.17	.....	.....	.....	.10	.13	.....	.09	.09	.12	12.6
Burgess well	.....	.....	.....	10.41	11.26	a0.10	.....	12.28	1.04	.....	.....	
Tide	.....	.....	.....	10.00	10.53	23.36	.....	11.55	.38	.....	.....	
Difference (lag)	.....	.....	.....	.41	.33	.34	.....	.33	.26	.....	.....	33.4
Lee well	.....	.....	.....	.....	.....	.....	.....	.....	.....	18.23	7.26	
Tide	.....	.....	.....	.....	.....	.....	.....	.....	.....	17.33	6.20	
Difference (lag)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.50	1.06	.58
Underhill well	21.25	10.17	.....	11.22	12.06	a0.55	.....	13.11	1.49	.....	.....	
Tide	20.10	9.04	.....	10.00	10.53	23.36	.....	11.55	.38	.....	.....	
Difference (lag)	1.15	1.13	.....	1.22	1.13	1.19	.....	1.16	1.11	.....	.....	75.6

a Morning of following day.



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Difference in time between high- and low-water stages in four artesian wells at Oyster Ba N. Y., and the tide in Oyster Bay Harbor.

[Time expressed in hours and minutes of 24-hour clock.]

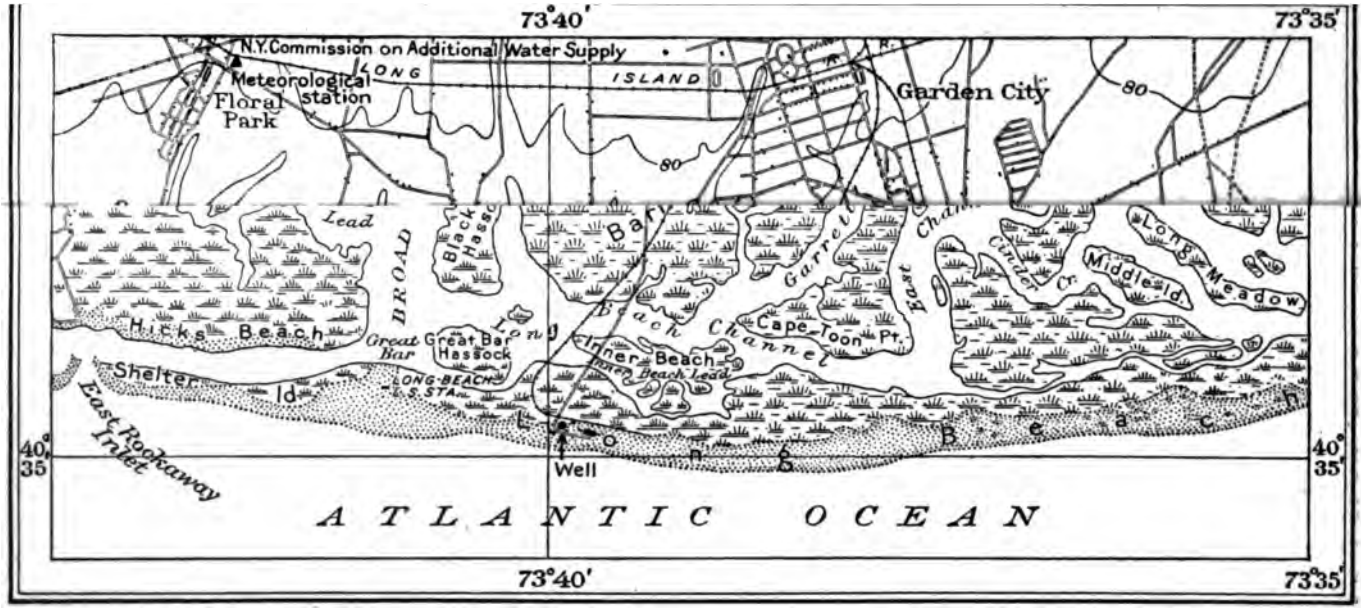
HIGH TIDES.

1903.	May 30.	May 31.		June 1.	June 2.		June 3.		June 4.	June 10.	June 11.	A a 1
Casino well	.....	.....	14.52	.....	.....	17.05	5.19	18.11	6.38	.....	12.22	
Tide	.....	.....	14.43	.....	.....	16.54	5.12	18.02	6.29	.....	12.20	
Difference (lag)	.....	.....	.09	.....	.....	.11	.07	.09	.09	.....	.02	
Burgess well	.....	.....	15.13	16.05	.....	17.15	5.38	18.25	6.56	.....	.....	
Tide	.....	.....	14.43	15.44	.....	16.54	5.12	18.02	6.29	.....	.....	
Difference (lag)	.....	.....	.30	.21	.....	.21	.26	.23	.27	.....	.....	2
Lee well	.....	.....	.....	.....	.....	.....	.....	.....	.....	a0.20	13.12	
Tide	.....	.....	.....	.....	.....	.....	.....	.....	.....	23.48	12.20	
Difference (lag)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.32	.52	
Underhill well	.....	.....	16.02	17.02	.....	18.00	6.20	19.10	7.41	.....	.....	
Tide	.....	.....	14.43	15.44	.....	16.54	5.12	18.02	6.29	.....	.....	
Difference (lag)	.....	.....	1.19	1.18	.....	1.06	1.08	1.08	1.12	.....	.....	7

LOW TIDES.

Casino well	20.28	9.21	.....	.....	.....	23.46	12.08	.....	0.47	17.42	6.32	
Tide	20.10	9.04	.....	.....	.....	23.36	11.55	.....	.38	17.33	6.20	
Difference (lag)	.18	.17	.....	.....	.....	.10	.13	.....	.09	.09	.12	1
Burgess well	.....	.....	.....	10.41	11.26	a0.10	.....	12.28	1.04	.....	.....	
Tide	.....	.....	.....	10.00	10.53	23.36	.....	11.55	.38	.....	.....	
Difference (lag)	.....	.....	.....	.41	.33	.34	.....	.33	.26	.....	.....	3
Lee well	.....	.....	.....	.....	.....	.....	.....	.....	.....	18.23	7.26	
Tide	.....	.....	.....	.....	.....	.....	.....	.....	.....	17.33	6.20	
Difference (lag)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.50	1.06	
Underhill well	21.25	10.17	.....	11.22	12.06	a0.55	.....	13.11	1.49	.....	.....	
Tide	20.10	9.04	.....	10.00	10.53	23.36	.....	11.55	.38	.....	.....	
Difference (lag)	1.15	1.13	.....	1.22	1.13	1.19	.....	1.16	1.11	.....	.....	7

a Morning of following day.



MAP OF PORTION OF SOUTHERN LONG ISLAND, SHOWING LOCATION OF HEWLETT, LONG BEACH, MILLBURN, AND LYNBROOK WELLS.

OBSERVATIONS WITH SELF-RECORDING GAGES.

INSTRUMENTS USED.

The continuation of the observations by means of self-recording gages was due to ıe timely interest of Mr. F. H. Newell and Prof. Charles S. Slichter. Mr. Newell

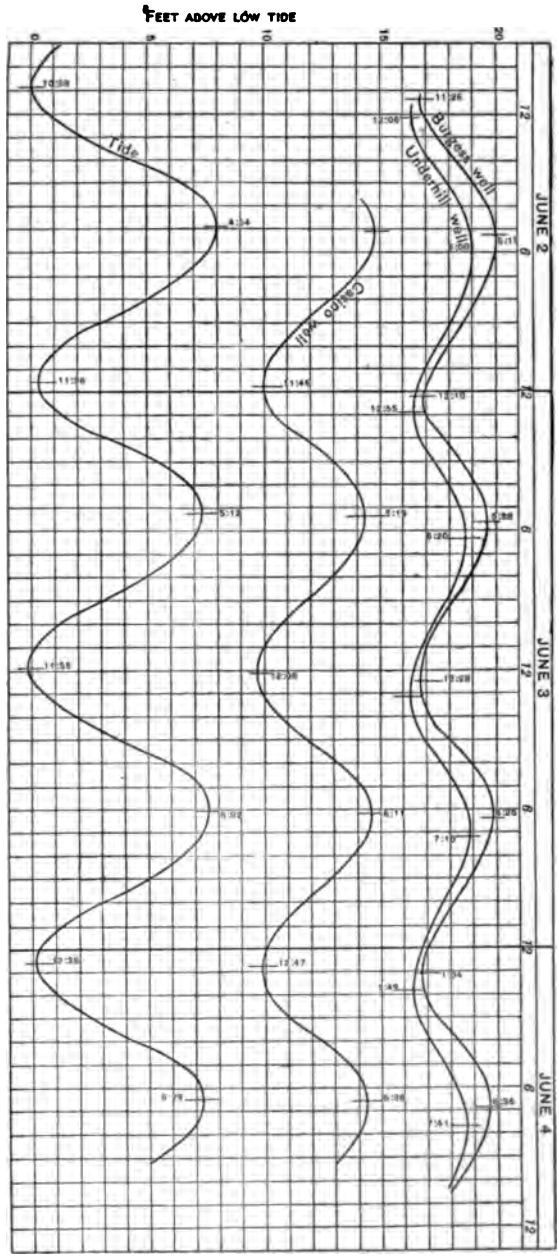


FIG. 8.—Well and tide curves at Oyster Bay, N. Y., showing tidal fluctuations due to plastic deformation. From observations with direct-reading floats by party in charge of Isaiah Bowman, under direction of A. C. Veatch.

sited the island when the observations at Oyster Bay were in progress, and at once rected that three Friez water-stage registers be purchased. These were supple-

mented by a gage constructed at Purdue University from the designs Mead.

Shortly after Mr. Newell's visit, and before the Friez gages had Prof. Charles S. Slichter arrived to take charge of the measurement underflow. He kindly obtained the loan of five of the gages used experiments at Madison, Wis.;[a] of these, four were week gages and gage. The King gages were constructed by H. Green, Brooklyn, f stands; they consist of an ordinary barograph cylinder, driven by a marine clock, the recording device being a simple lever on a cone bea on one end and a place for attaching the float on the other. At the p clock motion is transmitted to the drum there was a slight amount King found would introduce into the records an error of one to two tion brake was, however, subsequently added to overcome this defe as received on Long Island were adjusted to magnify the fluctuatior times; and as this scale was entirely too great for the wells observed extended until the ratio was 1:2 and a reduction of one-half the These gages were found to be more sensitive and reliable than any otl means of the simple lever with its cone bearing, the friction in thi reduced to a minimum; the pens respond to the slightest movemen and for the faithful reproduction of small fluctuations this simple ty be highly recommended.

In the Mead gage the recording drum is vertical and the pen is carri working between two upright guides. The wire supporting the carri a wheel connected with the wheel around which a wire from the floa lifted and lowered as the float descends and rises. The float and the the pen is attached are so related in diameter that the curve traced is 1 scale. There is with this gage, as with most gages where the record driven by the clock, some lost motion at the point of connection. larly bad in this instrument. On the Long Beach records great care ting the gage and the trouble was avoided, but some of the curves fro Douglaston, are clearly in error two to three hours.

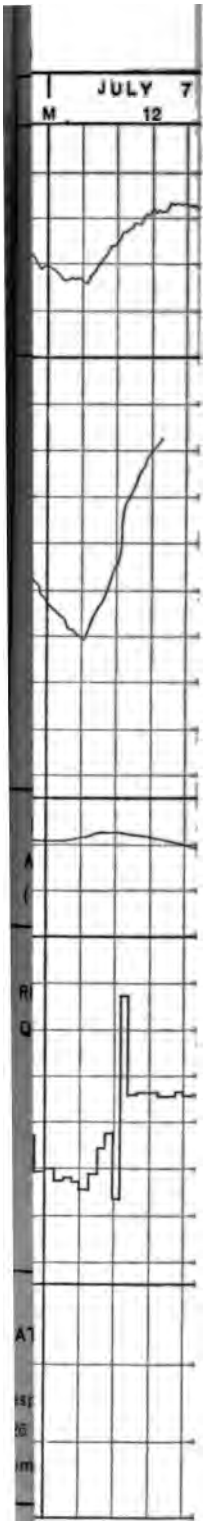
In the Friez gage[b] the recording drum is horizontal and is move while the pen is moved by the clockwork. It was found that with t that must be used in wells of small diameter the inertia of the drum ment was such that it would not move until considerable head was that small fluctuations were often not recorded. There was also amount of lost motion in the cogs used in the reducing device; and tric was provided for engaging the cogs closer, this could not be d increasing the friction that the instrument was useless. As a whole, sufficiently sensitive for this kind of work, and the time element is ent

A water-stage register manufactured by a western house was als results obtained were not satisfactory because of the poor mechanical the gage.

OBSERVATIONS ON WELL OF QUEENS COUNTY WATER COMPANY, 1 M HEWLETT, N. Y.

Through the kindness of the chief engineer of the Queens County W Mr. Charles R. Bettes, an artesian well 181 feet deep and 3,300 fe company's pumping station (Pl. II) was covered with a shelter for th the gages and placed at the disposal of the Survey. This well, as is the wells of about the same depth sunk near the pumping station, p layer of surface sand and gravel, then through beds of clay and othe

[a] Bull. U. S. Weather Bureau No. 5, 1892.
[b] Manufactured by Julian P. Friez, Baltimore, Md.



WLETT, N. Y.
is inverted.

into a rather coarse gravel, which yields an abundant supply of flowing water.[a] The whole section is of Pleistocene age. There are in the immediate vicinity of the pumping station thirty-two 5-inch wells, 33 feet deep, and nineteen 6-inch wells, 150 to 190 feet deep. These are arranged along two lines, one extending northwest and the other southwest from the pumping station. The extreme end of the south line is about 1,000 feet from the pumping station, and the well observed is therefore over 2,000 feet from the nearest pumped well and but slightly to one side of the probable direction of flow. (Pl. II.) It was the opinion of Mr. Bettes that this well was not affected by pumping, and through a misinterpretation of the first records it was believed that this surmise was correct. Considerable discussion was therefore caused when it was found that the well fluctuations simulated the thermograph curve in a remarkable manner, that these fluctuations were inversely related to the temperature (a rise in temperature causing a fall in water), and that the changes manifested themselves with a lag of but one or two hours behind apparently similar temperature fluctuations. (Pl. III.)

The hourly pumpage was kindly furnished by Chief Engineer Bettes, and this record, when plotted with the well curves, conclusively demonstrated that the rhythmical fluctuations were due more to pumpage than to temperature (Pl. III). Fluctuations of a somewhat similar character are produced by temperature changes (see p. 54), and this element is doubtless present in this curve. On Pl. III the effect of pumpage is clearly shown in the double cusps of the well curves on the night of July 5–6. The temperature curve shows no such variations. Similarly, the records on June 21, 25, and 26 show important differences between the well and temperature curves, which are largely due to pumping. These results are important because of the rapid rate of transmission. The effect of this pumping is felt at a distance of 2,000 feet or more, with a time lag of but one or two hours. This contrasts sharply with the very slow transmission noted in the pressure changes due to tidal loading and to the inflow and outflow along rivers (see pp. 60, 65). It conclusively proves that the supply here is large; that the beds are quite porous, and that the normal water flow is rapid.

In the records from the day gage, which was maintained here for the first ten days, the larger time scale brought out very clearly a series of regular minor fluctuations which were not clearly defined with the smaller scale of the week records. The most pronounced of this series recurs day after day and has a period of very nearly twenty minutes and a range of 0.06 to 0.08 inch.

Besides these vibrations, with a period of twenty minutes, there are several fluctuations of smaller amplitude and period. One series has a period of about five or six minutes, but it is so involved that little can be definitely stated regarding it. An instrument with a large time scale, 1 or 2 inches to the hour, and a vertical scale of once or twice the normal would record, at this place, a very complicated series of small recurrent vibrations.

OBSERVATIONS AT LONG BEACH, N. Y.

The deep flowing well of the Long Beach Association at Long Beach, N. Y. (Pl. II), offered a most excellent opportunity for the observations of tidal fluctuations. It is situated on a narrow, sandy barrier beach, separated from the main island by a sea marsh 2 to 3 miles wide, cut by narrow tidal channels, and is entirely removed from the influence of any pumping station.

This well is 3 inches in diameter and 386 feet deep. The water is obtained in sands of Cretaceous age and rises 2 to 4 feet above the surface of the ground or 10 to 12 feet above sea level. The general geologic relations may be inferred from the diagrammatic cross section given in fig. 1 (p. 9).

[a] For detailed record of strata in near-by wells see Prof. Paper U. S. Geol. Survey No. 44, 1906, p. 225, fig. 66.

The section reported by the driller, Mr. W. C. Jaegle, is as follows:

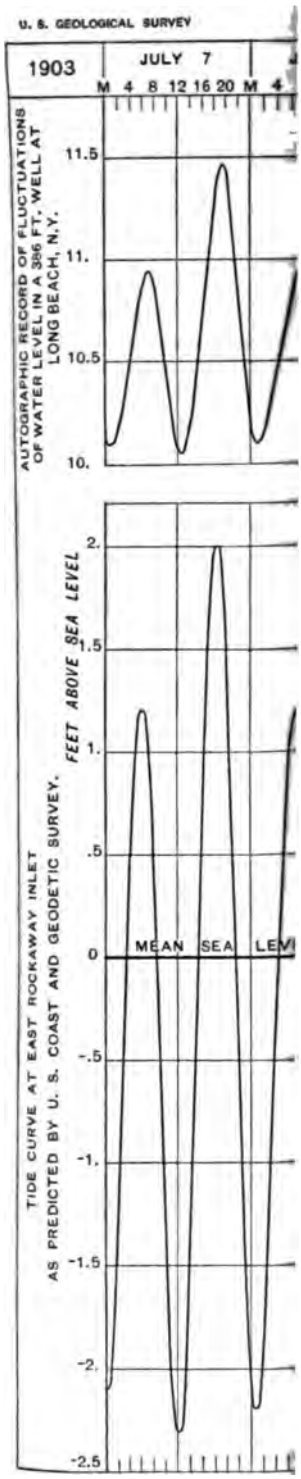
Section of well of Long Beach Association, at Long Beach, N. Y.

		Feet.
1.	White sand	0– 36
2.	Dark sand and creek mud	36– 40
3.	White gravel, containing salt water	40– 51
4.	White sand	51– 55
5.	Dark sand	55– 65
6.	White sand	65– 70
7.	White gravel	70– 73
8.	Yellow sand	73– 76
9.	Blue clay	76– 82
10.	Yellow gravel	82– 90
11.	Creek mud	90– 99
12.	Dark fine sand, containing lignite	99–101
13.	White sand	101–111
14.	Dark sand	111–119
15.	White sand, with lignite	119–121
16.	Blue clay	121–135
17.	Fine white sand	135–143
18.	Gravel, with salt water	143–145
19.	Dark sand	145–156
20.	Gravel, with salt water	156–158
21.	Clay	158–174
22.	White sand, containing at 190 feet a log of lignitized wood	174–192
23.	White gravel and salt water	192–196
24.	Clay	196–200
25.	Fine sand	200–220
26.	Solid blue clay	220–270
27.	White sand and wood, containing fresh water, sweet and chalybeate	270–276
28.	Clay	276–282
29.	White sand and wood	282–297
30.	Blue clay	297–305
31.	White sand, wood, and water	305–308
32.	Blue clay	308–317
33.	White sand, containing wood and artesian water	317–325
34.	Blue clay	325–340
35.	White sand and mineral water; has considerable CO_2, sparkling and effervescent	340–356
36.	Blue clay	356–360
37.	White sand and pure water	360–378
38.	Blue clay	378–380
39.	White sand	380–381
40.	White clay	381–383
41.	Fine sand, with artesian water	383–384

Mr. F. D. Rathbun was placed in charge of these observations and by a carefu readjustment of the Mead gage obtained very excellent curves (Pl. IV). Indeed for this character of work the results from the Mead gage, as set up by Mr. Rath bun, are better than from the Friez gage.

It was impossible to make tide observations at this point, and the values plotte on the curve are taken from those predicted by the Coast and Geodetic Survey[a] for East Rockaway Inlet, which is 2.8 miles west of the well. The difference in tim

[a] U. S. Coast and Geodetic Survey Tide Tables for 1903, p. 346.


U. S. GEOLOGICAL SURVEY
1903
JULY 7
M 4 8 12 16 20 M 4
AUTOGRAPHIC RECORD OF FLUCTUATIONS OF WATER LEVEL IN A 386 FT. WELL AT LONG BEACH, N.Y.
11.5
11.
10.5
10.
TIDE CURVE AT EAST ROCKAWAY INLET AS PREDICTED BY U. S. COAST AND GEODETIC SURVEY.
FEET ABOVE SEA LEVEL
2.
1.5
1.
.5
0
MEAN SEA LEVEL
-.5
-1.
-1.5
-2.
-2.5

PAR

ıe tide at this point and on the beach in front of the well is probably not two or three minutes, since at New Inlet, 5.3 miles east of the well, high les occur only from four to six minutes earlier than at East Rockaway Inlet. ; regarding the tidal fluctuations in the channel behind Long Beach are er. Mr. Paul K. Ames, of the Long Beach Association, through whose . was possible to make observations on this well, states that the amplitude in Broad and Long Beach channels is about 4 feet, or the average of the s in the open ocean at this point, and that in the tides behind Long Beach ag of about one hour.

.ions a few miles to the west in Jamaica Bay, which is separated from the ı by a sand bar similar to that at Long Beach, show that at various points : bar the high and low water are from thirty-two to eighty minutes behind stages in the ocean, and that the lag at high water is less by from six to utes than at low water.[a] It may be confidently affirmed that a similar lag he channels behind Long Beach.

curve obtained is a very smooth curve, which is apparently the simple f the tides in the ocean and those inside of the bar. The extreme regu- ıe low-tide values is believed to be due to the modifying influence of the ıe inner channels, which, because of the shallow character of the outlets ean, would have a much smaller low-tide variation than the ocean. The ıigh and low waters in the well, compared with the ocean tide, is given in ng table:

ing difference in time between high and low water in a 386-foot well at Long '. Y., and the tide as predicted by the United States Coast and Geodetic Survey Rockaway Inlet (Pl. IV).

Date.	High water.			Low water.		
	Well.	Tide	Differ-ence.	Well.	Tide	Differ-ence.
1903.	*Time*	*Time*	*Hours and min-utes*	*Time*	*Time*	*Hours and min-utes.*
.....	.....	.....	.....	18 30	18.09	0.21
.....	1.20	0.13	1.07	7.00	6.36	0 24
	.....	12.53	.....	19.50	19.10	0.40
.....	2.20	1.10	1 10	8 00	7 32	0.28
	15.20	13 52	1.28	20 50	20 14	0.36
.....	3 20	2.13	1.07	9 20	8.25	0.55
	16.10	14.49	1.21	22 00	21.16	0.44
.....	4 05	3.13	0.52	10 30	9.26	1.04
	17.05	15.46	1.29	.....	.....	.....
.....	7.05	5.58	1 07	0 40	23.59	0.41
	19.25	18.14	1.11	12 20	11.59	0.21
.....	7.35	6.44	0.51	1.10	0.44	0.26
	20 10	18 55	1.15	12 50	12.44	0.06
.....	8.35	7.25	1.10	2.00	1 24	0.36
	20.50	19.34	1.16	13.55	13.24	0.31
.....	9.15	8.03	1.12	2.50	2.02	0.48
	21.35	20.11	1.24	14.35	14.04	0.31
.....	9.55	8.38	1.17	3.20	2.36	0.44
	22.05	20.46	1.19	15.15	14.38	0.25
.....	10.40	9.09	1.31	3.40	3.11	0.29
	23.05	21.19	1.46	15.35	15.09	0.26

[a] U. S. Coast and Geodetic Survey Tide Table for 1903, p. 346.

Table showing difference in time between high and low water in a 386-foot well at Beach, N. Y., and tide at East Rockaway Inlet—Continued.

Date.	High water.			Low water.		
	Well.	Tide.	Difference.	Well.	Tide.	Di
1903.	*Time.*	*Time.*	*Hours and minutes.*	*Time.*	*Time.*	*H and*
July 13	11.50	9.44	2.06	4.50	3.44	
	23.00	21.54	1.06	16.55	15.44	
July 14	11.40	10.21	1.19	5.10	4.19	
	23.45	22.28	1.17	17.10	16.21	
July 15	.....	.....	.....	5.55	4.55	
	12.20	11.03	1.07	18.00	17.04	
July 16	0.30	23.09	1.21	6.20	5.34	
	.....	.....	.....	19.20	17.55	
July 17	1.10	23.56	1.14	7.20	6.27	
Average	.....	.....	1.19	.....	.....	

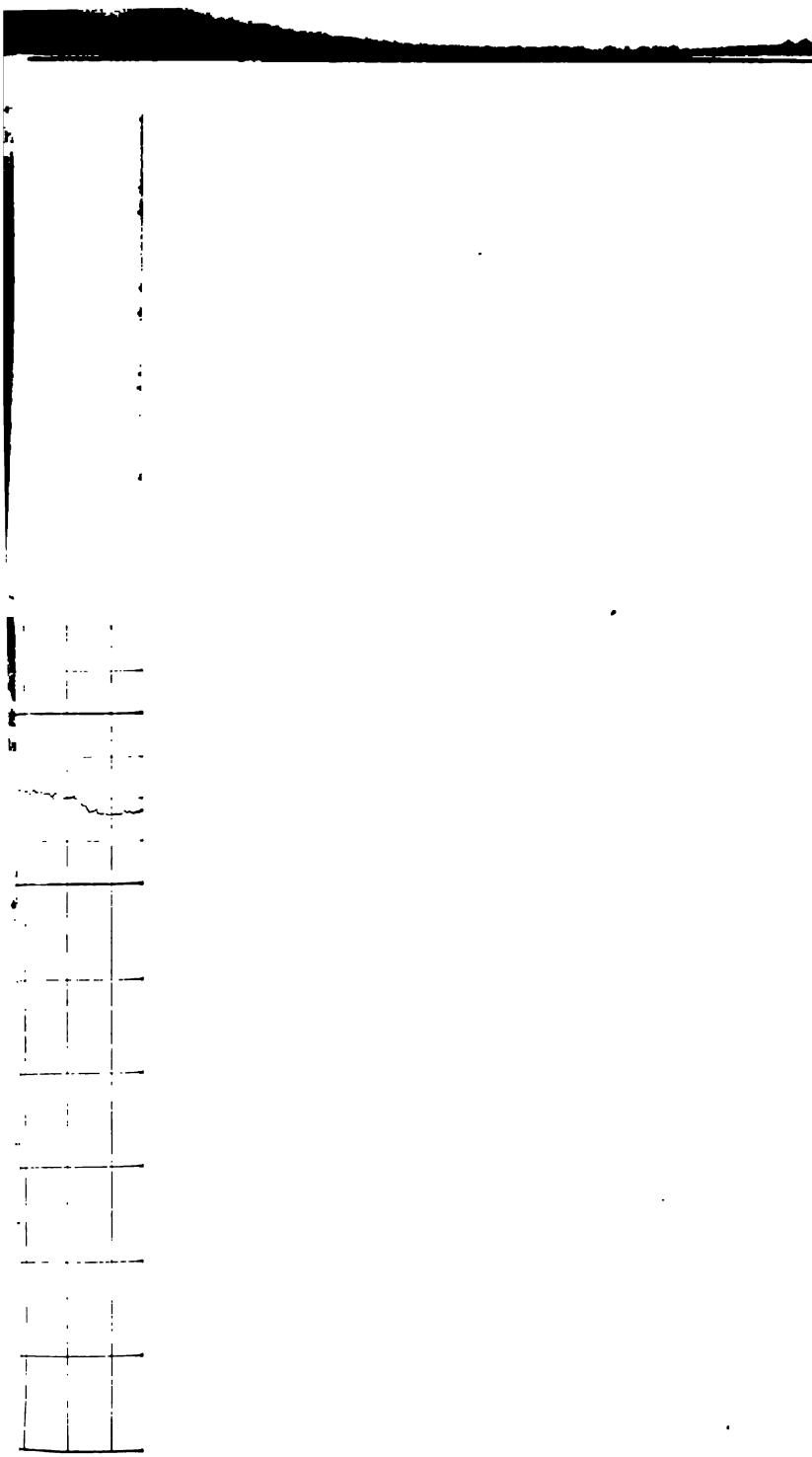
It will be noted that the lag at high water is greater than at low, which is j the reverse of what occurs in tidal rivers, where the water rises much more rapi than it falls and the low-water lag is long and the high-water lag short. This is important result bearing on the relation between the fluctuations of the wate wells and the oceanic tide and clearly refutes the doctrine that the tidal fluctuati here are due to leakage and that the fluctuations are analogous to those of ti rivers. (See pp. 63–67.)

OBSERVATIONS ON THE SCHREIBER WELL NEAR MILLBURN, N. Y.

This well is located on the very edge of the sea marsh, about 2 miles south of Ba win station on the Long Island Railroad (Pl. II). It is 8 inches in diameter a the total depth determined by sounding is 288.6 feet. The water will, when pi up, rise about a foot above the surface of the ground. After an unsuccessful atten to record the fluctuations here with a Friez gage, which gave no results becaus the small amplitude of the fluctuations, the King gage used on the Queens Cou Water Company well near Hewlett was set up and the record obtained from July to August 5. This record shows the most erratic fluctuations obtained on L Island (Pl. V).

In all the other records, while there are always many factors present, certain fl tuations can be definitely ascribed to temperature, atmospheric pressure, rainf pumping, or transmitted tides, but here either the curves produced by severa these factors have been so superposed that the character of each is thoroug masked or new factors have been introduced. The most evident characteristi these curves is the greater rapidity and abruptness in the fall of the water tha its rise. Abrupt drops of this character are known to be produced by change barometric pressure and by pumping. It will be noted in this case that these fl tuations are not represented in the barograph curve, and a comparison with record from the 504-foot well at Lynbrook (Pl. VI), in which the geologic co tions are very similar, shows no correspondence, although the Lynbrook wel clearly greatly affected by barometric changes.

The nearest pumping stations are at Rockville Center and Freeport, and these small village plants. At Rockville Center there were at this time four 8-inch we about 50 feet deep, and at Freeport 4 wells, about 35 feet deep. At Rockville Ce about 150,000 gallons per day were pumped, and at Freeport about 100,000. Th



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ations are, respectively, 1.9 and 2.4 miles from the Schreiber well (Pl. II). The ockville Center pumping station is, moreover, nearer the deep Lynbrook well than ie Schreiber well, and the Lynbrook well shows no such fluctuations. It is there-re believed that these fluctuations are not due to pumping.

A third hypothesis is that the fluctuations are largely tidal, and that they represent ie complicated stresses resulting from the culmination of the tides at different times i the neighboring network of creeks and channels. The conditions near this well e regarded as quite favorable for complex tides, but the resultant of these would represented by a smooth curve, as is shown by the Long Beach well. The normal dal curve in such narrow channels would, moreover, show a rapid rise and a gradual ll, while the well curve is just the reverse.

The fluctuations in this well are, so far as known, unique. The geologic condi-ons are believed to correspond in a general way with those in the 368-foot well at ong Beach and the 504-foot well at Lynbrook, both in the same region, but the aracteristics of the curves are entirely different and apparently not related to either.

OBSERVATIONS AT LYNBROOK, N. Y.

A station was established one-half mile west of Lynbrook (Pl. II). At this point iere were two test wells, one 504 feet deep and the other 72 feet, belonging to the ueens County Water Company. Through the kindness of Mr. Franklin B. Lord, resident, and Mr. Charles R. Bettes, chief engineer, these wells were covered with shelter, and a third well, 14 feet deep, driven about 6 feet from the other two. his gave a shallow surface well, a "deep well" (comparable to many of those used the Brooklyn waterworks pumping stations west of this point) which flowed at ie surface for about half the time, and a very deep artesian well, all within a few et of each other and away from the zone of influence of any pumping station.

About 15 feet from the wells there is a small ground-water fed brook, the bottom of hich has an elevation of about 10 feet above sea level; the ground at the wells is .3 feet above sea level, and the crest of the low swell, 1,000 feet to the west, about feet (Pl. II, p. 16). The surface material is yellow loam, ranging from a few ches to 3 feet thick, then rather coarse sand and gravel. No record was preserved the strata penetrated in the 72- and 504-foot wells, but a new well sunk during the mmer of 1904, about 300 feet west of this group of wells, gave the following section:

ction of well of Queens County Water Company, one-half mile west of Lynbrook, N. Y.

	Feet.
sbury:	
1. Coarse yellow quartz sand; no erratic material	0–29
2. Light-gray sand	29–31
3. Same as No. 1	31–73
retaceous?:	
4. Light-gray silty clay	73–89
5. Light-yellow medium sand; no erratic material	89–150
retaceous:	
6. Fine to medium gray lignitic sand	150–158
7. Very fine black micaceous lignitiferous silt	158–200
8–9. Very fine dark-colored lignitiferous sand	200–228
10. Medium light-gray sand, with small amount of lignite	228–340
11. Dark-colored lignitiferous silty clay	340–363
12. Medium dirty-yellow sand, lignitic	363–403
13. Medium to coarse gray sand	403–536

The water in the 504-foot well, during the time of observation, stood from 0.8 foot 2.2 feet above the surface; in the 72-foot well from 0.6 foot below to 0.5 foot above ie surface, and in the 14-foot well from 0.6 foot below to 0.2 foot above the sur-

face. The water in the 14-foot well rose above the surface three or four time periods of a few hours. The elevation of the water table under the low swell t west was probably about 13 feet.

Mr. Francis L. Whitney was placed in charge of the observations at this point King gages were installed on supports clamped to the well casings. The gages maintained from June 25 to September 15, and some of the results are give Pl. VI. These give a large amount of important material bearing not only on pa scientific problems, but on some of the live economic problems of the region. It be noticed that as a whole the curves of these wells are parallel. This bears directly on the old question of the source of the water in the deep wells on I Island. It has long been a favorite hypothesis that in some mysterious way l quantities of water were introduced by great underground streams from the England States, and this 504-foot well was one of the wells which were suppos strike one of these streams. It has already been shown[a] that the source of the w in the deep wells on Long Island is from the rain that falls on the surface (see p. and the really remarkable agreement of the general shape of these curves furni additional confirmation, pointing as it does to close interrelation and a com source.

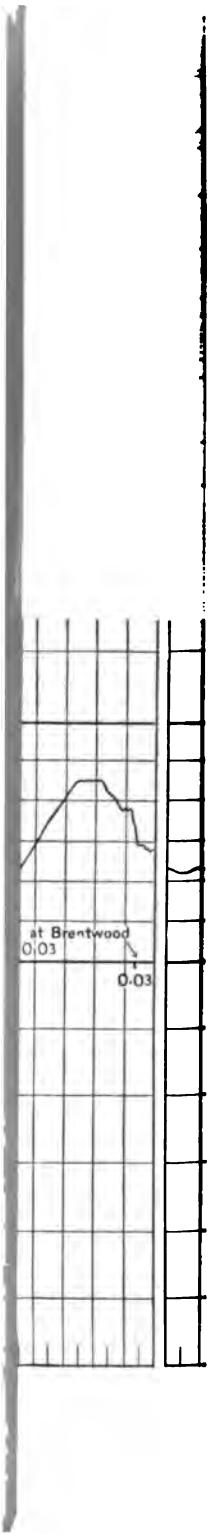
The behavior of these wells during rain storms shows that rain may affect water level in wells in two ways, (1) without the water reaching the ground-w table, and (2) by actual infiltration and addition to the ground water. In cases the effect is greatest in the shallow well. In the first case all wells comm to rise as soon as the rain begins, and rise abruptly, sometimes several inches. this can not be due to actual infiltration is shown by its instantaneous character by the fact that the water in the shallow 14-foot well, driven entirely in sand, above the surface of the ground four times under such circumstances. Such r moreover, produce no permanent deflection of the well curve. (See record for 18–22, Pl. VI.)

This sudden rise is due to a number of factors. In the first place, when the above the water table is filled with air the addition of water to the surface pr cally seals the outlets for the air and the weight of the rain is transmitted by confined air to the water table. The effect of such a transmission is to haster discharge of the water at the ground-water outlet, and so produce an immediate in the streams. In this manner rains which never reach the ground-water t and which do not contribute directly to stream flow may immediately produ greatly increased stream discharge. It should be noted in this connection that well always rose before the adjacent brook, although the brook might later rea higher elevation.

In the second case, when the water in the wells is elevated by the actual per tion of water, the water rises gradually and reaches its highest point several da weeks after the rain, rather than in several minutes. In the case of the heavy r which occurred on August 28, the 14-foot well reached its highest point before r on the 29th, the 72-foot well at about 6 o'clock on the 29th, and the 504-foot we noon on the 30th. There are three factors concerned in this last rise: (1) instantaneous transmission of pressure due to weight of rain on the surface in vicinity of the well; (2) actual percolation in the vicinity of the well, and (3) gressive deformations resulting from the weight of the rain at more distant po The rise in the deeper wells is wholly due to the first and third causes. The c in this case is actually displaced and returns to its former position only gradu instead of at once, as in the case described above.

Barometric changes affect the 504-foot well most, but are occasionally percep in the 72-foot well. Temperature changes produce rhythmical daily fluctuation the 14- and 72-foot wells; in the first the changes are very pronounced, amour

[a] Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 67–69.


at Brentwood
0.03
0.03

s much as 1½ inches a day. The 504-foot well showed a regular fluctuation with high and two low waters a day. The fluctuation, however, is not progressive, so is not tidal.

he curve from the 504-foot well shows a great number of minor periodic oscilla- s, but the time scale is not sufficiently great to study them satisfactorily. The t pronounced of the series has a period of about forty minutes. The 72-foot well sionally shows well-marked secondary oscillations, with a period of approxi- ely eighty minutes. For a careful study of these, however, a much larger gage a large time scale is demanded.

OBSERVATIONS AT DOUGLASTON, N. Y.

the winter of 1902 and 1903 a number of shallow wells were sunk along the base ills, east of Alley Creek, and near "The Alley," an old settlement just south of glaston, N. Y. (Pl. VII), for the Citizens' Water Supply Company. Six of these flowing wells, and in the other two the water comes very near the surface. Through kindness of Mr. Cord Meyer and his son, Mr. J. Edward Meyer, president and erintendent, respectively, of the Citizens' Water Supply Company, the flowing ls were piped up beyond the limit of flow and thus prepared for gaging.

he relative elevation, depth, and head in these wells are shown in the following e:

Elevations in wells of Citizens' Water Supply Company, at Douglaston, N. Y.

	Elevation of surface above sea level.	Depth of bottom of pipe below sea level.	Average height above sea level to which water will rise if piped up.
	Feet.	*Feet.*	*Feet.*
y Pond	17.2	.....	17.2
No. 1	20.2	20.5	19
No. 2	10.2	25	9
No. 3	5	28	8.5
No. 4	5	25	18
No. 5	10.8	39	18
No. 6	10.1	35	19
No. 7	9.8	30	17
No. 8	10.5	17	15

he strata encountered vary considerably; some of the wells penetrate nothing sand and gravel, and in others clay beds of greater or less thickness are found. water is derived from the adjacent hill mass, the height of the ground water in ch determines the head in these wells.

he tidal marsh to the west is a mass of soft black mud largely covered with a mat rowing vegetable matter, which is sufficiently firm to walk on, but which gives at ry step. This surface mat of roots is often sufficiently tenacious to hold up when lermined by the small streams formed by the many springs that occur at the base he hills, and these streams often flow through underground passages beneath the . The underlying mud or black ooze is over 10 feet thick in the upper end of mud flat, and Mr. D. L. Van Nostrand states that, in driving piles for a dock he bridge, the depth to "solid ground" was found to be 65 or 70 feet. The arte- pressure beneath this mud has caused the ground to rise in several places, with resultant production of many small rapids (Pl. VII). At a number of points r the upper end of the basin, where the mud is thin, the water has broken

through and produced low mud cones or mud volcanoes.[a] The drilling of the artesian wells and the fact that they were allowed to flow freely have perhaps in part relieved the pressure here, and during the three months the cones were observed they did not change materially, although on several occasions mud was seen rising from the craters and flowing down the sides. Three hundred feet north of the mud flat and on the east bank of Alley Creek there is a lesser area of mud which is not covered at low tide. In this there is a marked mud flow, which is likewise probably connected with the artesian waters under discussion.

Mr. Francis L. Whitney was placed in charge of the work here, and he prepared wooden shelter boxes covered with tarred paper. These were securely clamped to the top of the well pipes, which were steadied by means of guy lines.[b] A tide gage was established on the end of the crib of the drawbridge on the main turnpike. (Pl. VII.). The crib furnished a very good still box, and the locality is as near the wells as it was possible to get, for to the south the creek bed is uncovered at low tide.

The equipment consisted of 3 Friez gages and 1 Mead gage. The Mead gage was placed on well No. 8 and furnished the only record running through the whole of the time of observation. One of the Friez gages was placed at the drawbridge during the whole period, but from one cause and another no record was obtained before August 6, and after that time the record was not complete. By shifting the remaining gages records were obtained for a time from all the wells but No. 3. Some of the curves obtained from these observations are shown in Pl. VIII.

All these wells are clearly tidal, but when the question of the rate of propagation of tidal effect is considered many difficulties are encountered and the extreme complexity of the problem at once becomes evident. The curves, while broadly resembling each other, show many minor points of difference, which must be attributed to the varying shape of the tidal wave in the mud flat near the wells and the consequent complexity and variation of the stresses involved. Thus the records from wells 2 and 8 show that, while the relative amplitudes of the high tides agree perfectly and both show a tendency toward a double cusp at high tide, in well No. 2 the second cusp is characteristically greater, while in well No. 8 the first cusp is often the greater; compare curves from July 27 to 29. The low-tide curves also show marked differences; thus, in well No. 2 there is a continued fall until the tide turns, which it does sharply; in No. 8 there is a long period of stagnation and the curve is rounded when the rise begins. Evidently these curves are not readily comparable with the tide gage at the bridge nor with each other, for each represents the resultant of a different set of forces. The conditions for the production of such differences are very favorable. The semiliquid marsh mud yields readily to all pressure changes, however slight; the liquidity of the mud varies greatly from point to point, and while the artesian water does not commonly escape through the mud covering it may, as shown by the mud cones, do so at any time, and such a point of relief would affect adjacent wells differently.

Another factor making exact time comparisons difficult is the small scale of the records and the great amount of lost motion in the Mead gage. The Mead records show unquestionable time errors of one to two hours, and for this reason the end values are more important than the initial ones of each record. Where evident errors occur in the record of the Mead gage for well No. 8 they have been corrected as far as possible, and an attempt has been made to indicate on the diagram the various details affecting the time values so far as known. For this purpose the end of each of the original record sheets has been indicated on Pl. VIII.

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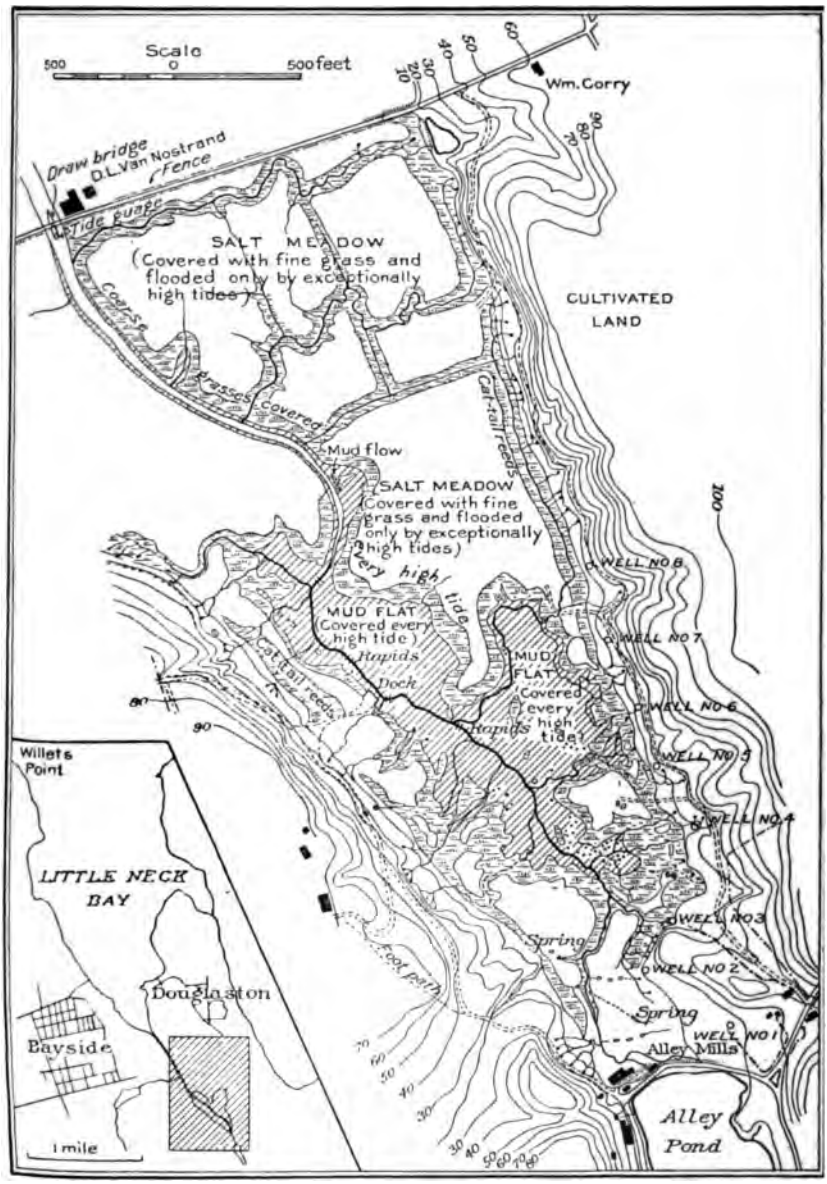
[a] See Prof. Paper U. S. Geol. Survey No. 46, 1906, Pl. XXVII, C.

[b] An illustration of the gage box on well No. 4 will be found in Prof. Paper U. S. Geol. Survey No. 44, 1906, Pl. XIV.



SKETCH MAP SHOWING LOCATION AND TOPOGRAPHIC SURROUNDINGS OF WELLS OF CITIZENS' WATER SUPPLY COMPANY NEAR DOUGLASTON, N. Y.

Black dots indicate location of mud volcanoes.
By A. C. Veatch, 1903.

SERVATIONS OF THE NEW YORK CITY COMMISSION ON ADDITIONAL WATER SUPPLY.[a]

ng Island division of the commission on additional water supply under the of Mr. W. E. Spear, division engineer, during the period from the middle) the last of October, 1903, made many observations on the water level in Long Island. In all about 1,200 wells were observed at intervals of from ee days by means of steel tapes fitted with cup sounders. From these ons Mr. Spear endeavored to obtain the velocity of the downward capillary e water on Long Island.

ological stations, equipped with self-recording instruments, were established rood and Floral Park (Pl. I, p. 9). It was from these records that the aph, barograph, and rainfall curves shown on Pls. III, V, and VI were

ar likewise obtained from the records of the Brooklyn waterworks data the fluctuations of the water in shallow wells on the south shore and the umping at Merrick and Agawam.

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alter E., Long Island sources: Rept. Commission on Additional Water Supply for the City k, Nov. 30, 1903, New York, 1904, appendix 7, pp. 617-806

PART II.

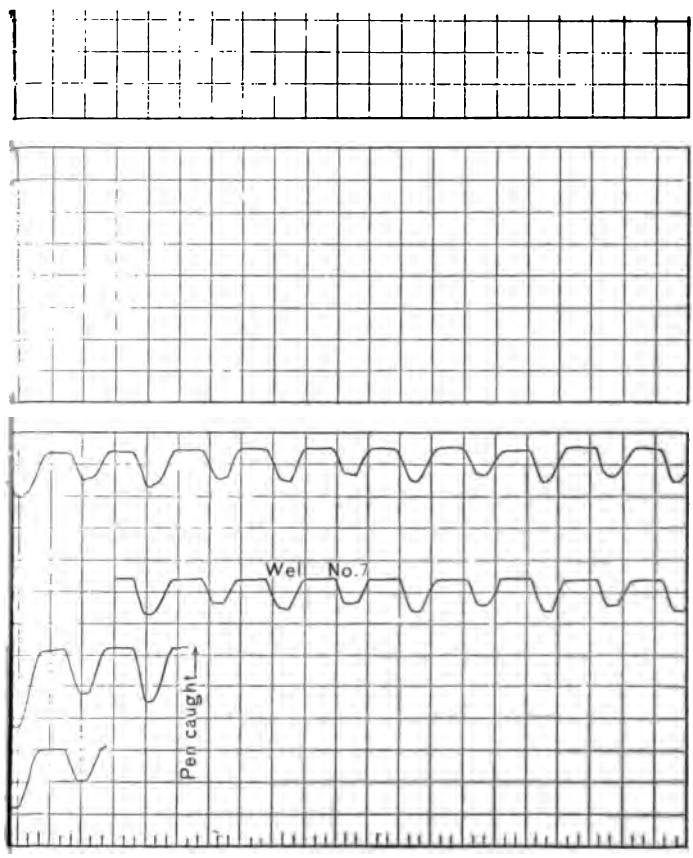
GENERAL DISCUSSION OF THE FLUCTUATIONS OF WATER LEVEL IN WELLS.

CLASSIFICATION OF CAUSES.

The vertical fluctuations of the ground-water table or the changes in the level of the water in wells may be grouped as follows:

A. Fluctuations due to natural causes.
  I. Rainfall and evaporation.
    1. Fluctuations not depending on single showers.
      a. Regular annual fluctuations.
      b. Irregular secular changes.
    2. Fluctuations produced by single showers.
      a. By transmission of pressure without any actual addition to the ground water.
      b. By the actual addition of rain to the ground water.
  II. Barometric changes.
  III. Thermometric changes.
    1. Fluctuation directly related to temperature.
    2. Fluctuation inversely related to temperature.
      a. At the surface of the ground-water table, directly through temperature changes.
      b. In deeper zones, by pressure changes produced by fluctuations of the preceding class.
  IV. Fluctuations produced by adjacent bodies of surface water: Rivers, lakes, the ocean.
    1. By changes in rate of ground-water discharge.
    2. By seepage.
    3. By plastic deformation due to varying loads.
  V. Fluctuations due to geologic changes.
B. Fluctuations due to human agencies.
  1. Settlement, deforestation, cultivation, drainage.
  2. Irrigation.
  3. Dams.
  4. Underground water-supply developments.
  5. Unequal loading.
C. Fluctuations due to indeterminate causes.

The relation between the fluctuations due to natural causes may be stated in this way: On the broad and irregular curves produced by the secular climatic and geologic changes are superposed the regular annual fluctuations, which are perhaps the most characteristic and important of the ground-water fluctuations due to natural causes; and on these, in turn, are superposed the simple rainfall, barometric, thermometric, tidal, and flood fluctuations. This complex curve, made up of many regular and irregular elements, is further modified by human agencies. The cumulative effect of these human agencies is irregular and the result is to modify—indeed, often to largely alter—the character of the broad irregular curves produced by secular climatic and geologic changes. Yet some of these human modifications have a periodic value which, in the case of cultivation, for example, may greatly change the amplitude of the annual fluctuations, or, in the case of pumping or the change of water level behind a milldam, may give rise to rather regular daily fluctuations.



F TIDE IN ADJOINING CREEK.

ges. At point marked * on well curve No. 8 lost motion is evide-
original record sheets.

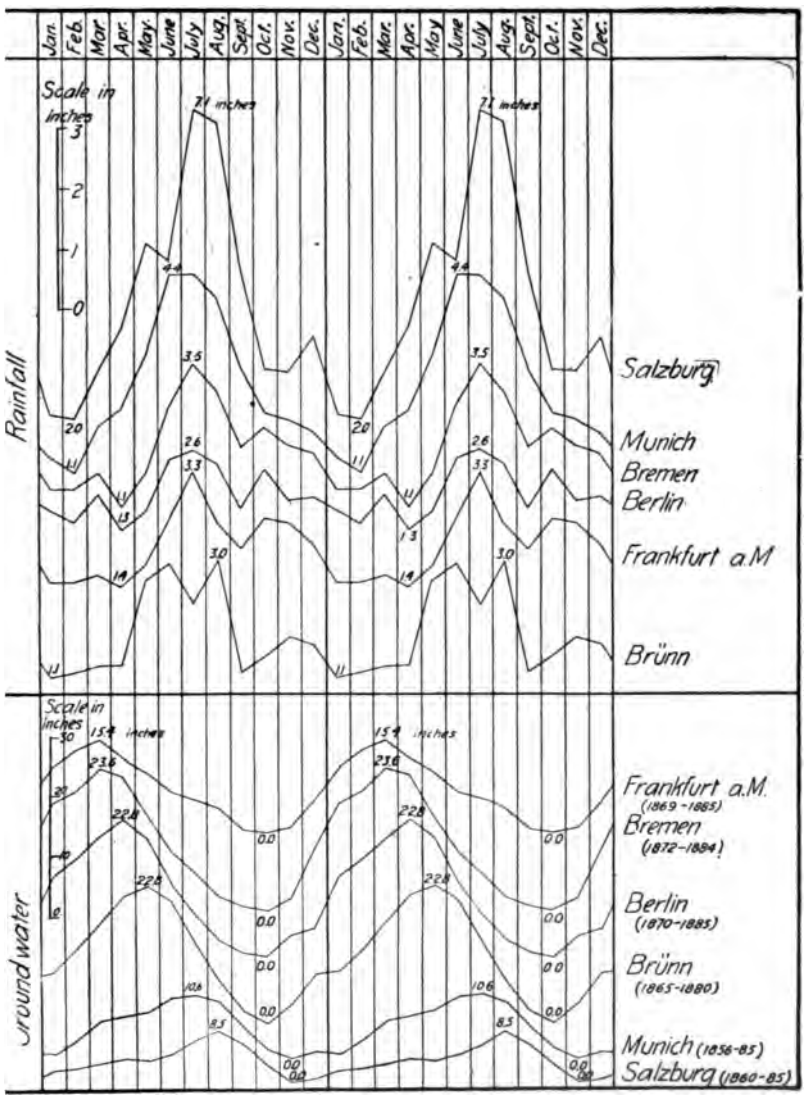
FLUCTUATIONS PRODUCED BY NATURAL CAUSES.

RAINFALL AND EVAPORATION.

REGULAR ANNUAL FLUCTUATIONS.

GENERAL CHARACTER AND CAUSE.

Woldřich, from a study of nine years' observations on a 19-foot well at Salzburg, concluded that the rise and fall of the ground water stands in no relation whatever to the



. 9.—Yearly rainfall and water-level curves in shallow wells in middle Europe (after Soyka). The curves are duplicated for a second year to facilitate comparisons.

ount of rain, since with the same quantity of precipitation it at times rises, and again s, and even with considerably increasing quantities of rain it often falls constantly.[a]

Woldřich, Johann Nepomuk, Mitt. d. Techn. Klubs zu Salzburg, 1869, Heft 1, Zeitschrift d. erreichischen Gesellschaft fur Meteorologie, Bd. 4, 1869, pp. 273-279 Penck's Geographische andlungen, Bd. 2, Heft 3, Wien, 1888, p. 23.

While so broad a statement is not entirely true for all localities in the North Temperate Zone, yet it properly emphasizes the fact that the relation between the ground-water fluctuations and the rainfall is not the simple one which might be inferred from the statement that the rainfall is the source of the ground water. Observations at many points in the North Temperate Zone have shown that the

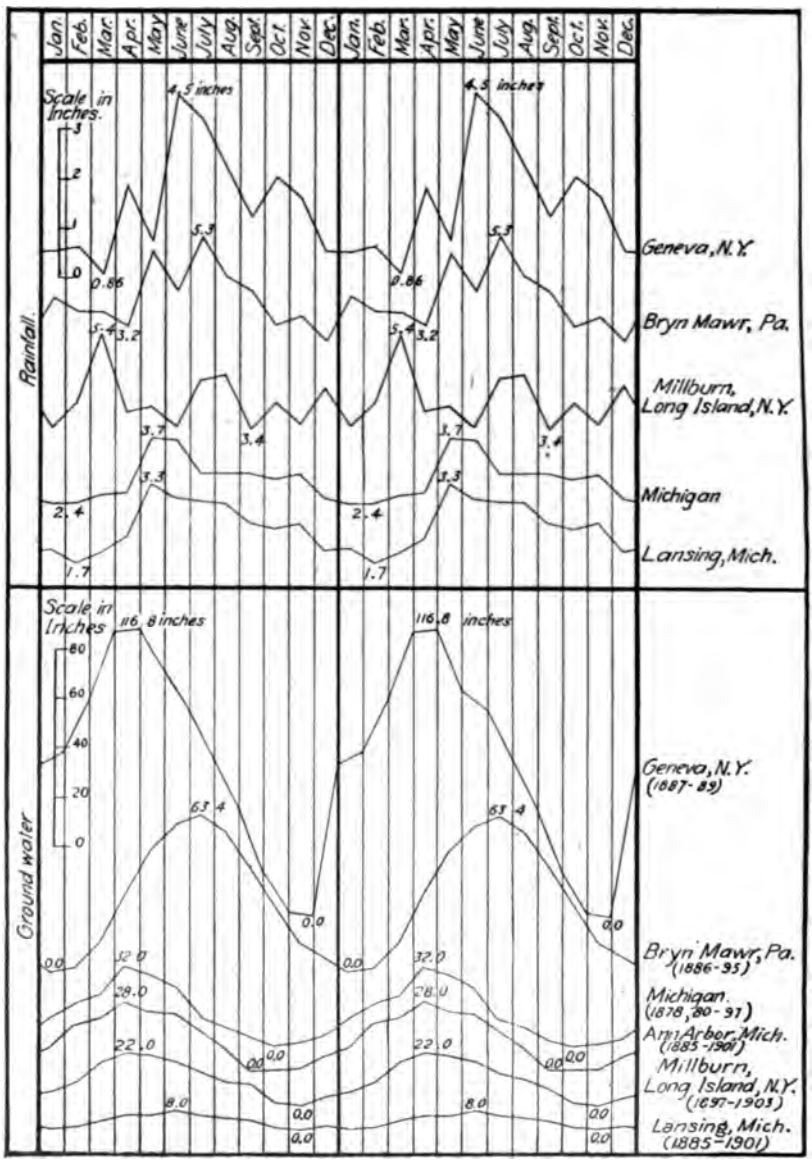


FIG. 10.—Yearly rainfall and water-level curves in shallow wells in the United States. The curves are duplicated for a second year to facilitate comparisons.

ground water fluctuates in a yearly period with a single maximum and minimum, and that this curve generally does not correspond with the rainfall curve (figs. 9, 10). Indeed, at Frankfurt, Bremen, Berlin, and Brünn, the highest point of the ground water is in the spring months at the time of least rainfall (fig. 9). The yearly

curves of the ground water are much more regular than the rainfall curve, and on the whole in general shape they most resemble the annual temperature curve (fig. 11). The reason for this difference is the simple one that the fluctuations of the ground water depend not only on the absolute amount of the rainfall, but on the quantity that reaches the zone of complete saturation, or the ground-water table, and the time consumed in so doing. The quantity is affected by many factors, among which are the evaporation from the surface of the ground, the evaporation or transpiration from plants, the quantity retained in the soil above the zone of saturation, and the amount that runs directly off the surface without ever penetrating the ground. The time element is affected by the porosity and moisture content of the soil, the character of the covering, and to a greater or less extent by the height of the soil column. The general result is that the water is delivered gradually to the zone of complete saturation, and as the effects of single rains are thus generally

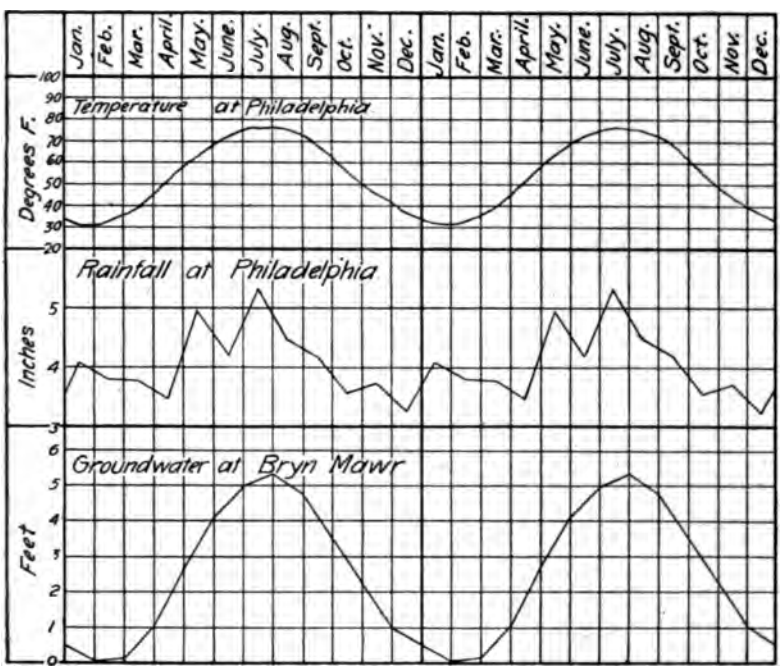


FIG. 11.—Annual curves based upon mean monthly averages of ground-water level at Bryn Mawr, Pa.,[a] and temperature and rainfall at Philadelphia, Pa.,[b] for the period 1886–1895, showing the general resemblance of the ground-water and temperature curves. The exact agreement of the maximum ground-water level and the maximum temperature is unusual.

minified and often entirely blotted out, a relatively smooth curve results (Pl. IX). This yearly period of the ground water is largely due to the periodic character of the evaporation, including plant transpiration. This depends on the temperature, and the net result for the year is a simple curve of the same shape as the mean temperature curve, although inversely related to it, hence the general resemblance of the yearly well curve to the temperature curve. Were the rain uniform throughout the year, and were there no lag due to transmission or unmelted snow, the maximum ground-water level would occur at the time of the minimum temperature and saturation deficit of the atmosphere, or, in the North Temperate Zone, in January. The effect of the irregular distribution of the rainfall is to change the time of the occurrence of this maximum. A moderate excess of rain in the summer, such as occurs

[a] Observations of W. S. Auchincloss; Waters within the Earth and Laws of Rainflow, 1897.
[b] Observations of U. S. Weather Bureau; Annual Summary Pennsylvania Climate and Crop Service.

at Frankfurt-am-Main, causes the maximum to advance to March, while at Bremen, Berlin, and Brünn, where the difference between the summer and winter rainfall is progressively greater, in the order named, the maxima occur respectively in March, April, and May (fig. 9). The extremely great summer precipitation at Munich and Salzburg, together with the low rainfall in January, causes the maximum at those places to advance to July and August.

In this connection the observations of (1) Dickinson and Evans, (2) Greaves, and (3) Lawes and Gilbert, near London, are of great interest. All of these observers endeavored to determine the amount of rain actually contributed to the ground

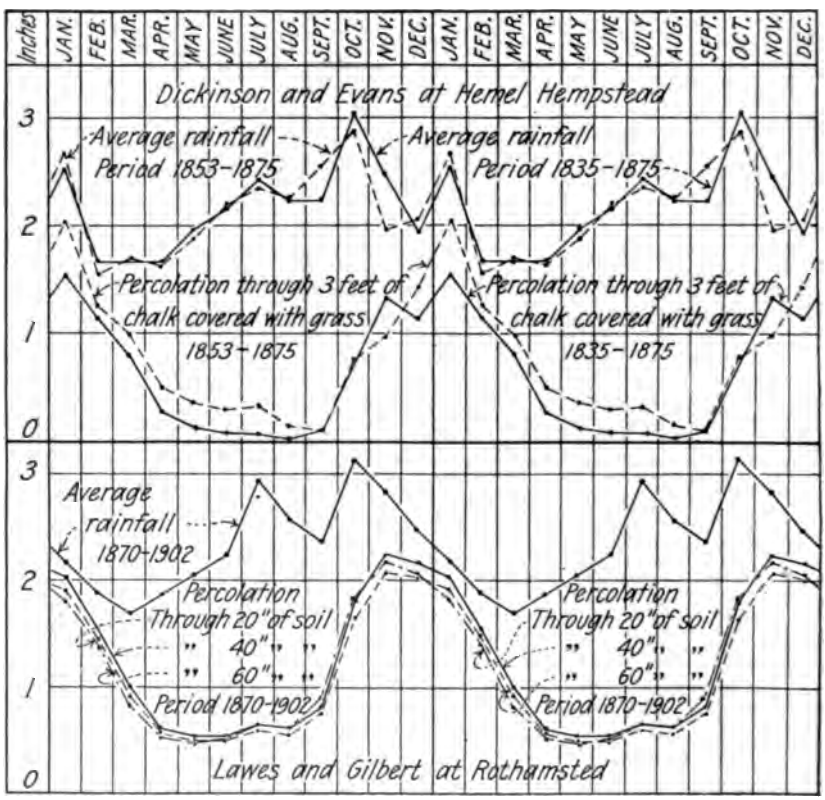
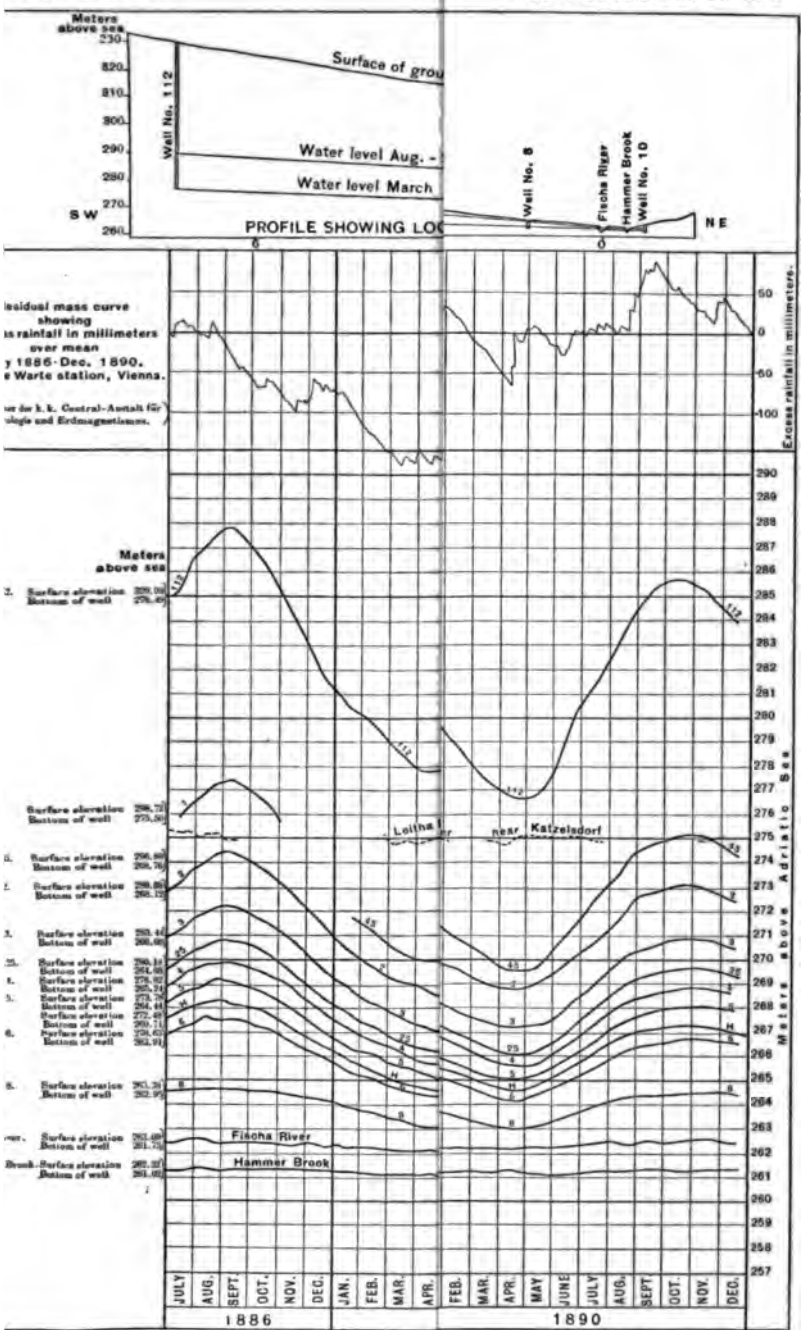


FIG. 12.—Results of English percolation experiments. In the Dickinson and Evans experiments the gages were buried in the ground; one was filled with ordinary Hertfordshire soil (a sandy, gravelly loam) and covered with sod; the other was filled with chalk and covered with a thin layer of soil and sod. In the Lawes and Gilbert observations columns of a rather heavy loam with clay subsoil in their natural state of consolidation were built in with brick and cement; no vegetation was allowed to grow on the gages, which were surrounded by meadow land. Curves are based on the monthly averages from September 1, 1870, to August 31, 1902.

water. Each used vessels with impervious sides and pervious bottoms, sunk level with the surface of the ground. The water percolating through the soil columns was collected and compared with the yield of the adjacent rain gages. In the case of the Dickinson and Evans and the Greaves experiments the boxes were filled with material supposed to represent the average soil of the region, in both cases a sandy loam. In the Lawes and Gilbert experiments actual blocks of soil were undermined and the results represent the amount of rainfall passing through a heavy loam with a clay subsoil in its natural condition of consolidation, but not covered with vegetation. The average results obtained are given in the following table and are partially shown in a graphic manner in fig. 12.



This illustrates regular annual fluctuations, irregular secular ows that the well fluctuations are generally independent of single rains. It also shows concentric time of occurrence of the yearly maximum and minimum. (From Bericht des Ausschusses für die

English experiments showing average amount of rain passing through soil during the different months of the year.

	Dickinson and Evans.[a]						Greaves.[b]					Lawes and Gilbert.[c]						
	1835-1875.			1853-1875.									Percolation through column of heavy loam with clay subsoil.			Percentage of rain percolating through—		
	Rainfall (average).	Percolation through 3 feet sandy loam covered with grass.	Percentage of percolation to rain.	Rainfall (average).	Percolation through 3 feet chalk covered with grass.	Percentage of percolation to rain.	Rainfall.	Percolation through 3 feet sandy loam covered with grass.	Percolation through 3 feet bare sand.	Percentage of rain percolating through soil.	Percentage of rain percolating through sand.	Rainfall (average 1870-1902).	20 inches deep.	40 inches deep.	60 inches deep.	20 inches.	40 inches.	60 inches.
	Inches.	*Inches.*	*Per ct.*	*Inches.*	*Inches.*	*Per ct.*	*Inches.*	*Inches.*	*Inches.*	*Per ct.*	*Per ct.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Per ct.*	*Per ct.*	*Per ct.*
January	2.54	1.55	61.0	2.68	2.05	76.5	2.000	1.250	1.875	62.5	93.8	2.17	1.80	2.02	1.90	82.9	93.0	87.6
February	1.67	1.14	68.3	1.55	1.26	81.3	1.375	.750	1.250	52.7	90.9	1.87	1.40	1.55	1.45	74.9	82.9	77.5
March	1.68	.79	47.0	1.70	.99	58.2	1.750	.750	1.625	42.8	92.8	1.69	.81	1.00	.92	47.9	59.1	54.4
April	1.66	.24	14.4	1.63	.49	30.0	1.500	.250	1.250	16.7	83.3	1.86	.52	.60	.56	27.9	32.2	30.1
May	1.97	.11	5.6	1.88	.34	18.0	2.250	.125	1.875	5.5	83.3	2.05	.48	.54	.49	23.4	26.3	23.9
June	2.15	.07	3.3	2.18	.29	13.3	2.125	.125	1.625	5.8	76.5	2.23	.51	.54	.50	22.9	24.4	22.4
July	2.43	.06	2.5	2.34	.31	13.2	2.125	.125	1.125	5.9	52.9	2.93	.65	.65	.60	22.2	22.2	20.5
August	2.23	.01	0.4	2.24	.13	5.8	2.625	.125	2.000	4.8	76.0	2.56	.61	.61	.56	23.8	23.8	21.9
September	2.22	.09	4.0	2.57	.09	3.5	2.125	.250	1.625	11.8	76.5	2.35	.90	.81	.77	38.3	34.5	32.8
October	3.05	.73	23.9	2.88	.74	25.7	3.000	.750	2.375	25.0	79.1	3.12	1.81	1.79	1.61	58.0	57.4	51.6
November	2.46	1.33	54.0	1.95	.98	50.2	2.125	1.250	2.000	58.8	94.0	2.81	2.17	2.24	2.07	77.2	79.7	73.7
December	1.92	1.13	58.0	2.06	1.43	69.4	2.000	1.250	1.375	62.5	68.8	2.46	2.05	2.17	2.03	83.3	88.2	82.5
Year	25.98	7.25	27.9	25.66	9.10	35.4	25.000	7.000	20.000	28.0	80.0	28.10	13.71	14.52	13.46	48.8	51.7	47.9

[a] Min. Proc. Inst. Civil Eng., vol. 2, 1843, pp. 160-161; vol. 9, 1850, p. 158; vol. 20, 1861, pp. 219-222; vol. 45, 1876, pp. 208-216.
[b] Artificial values based on twenty-two years' observation on soil and fourteen years on sand: Min. Proc. Inst. Civil Eng., vol. 45, session 1875-76, pt. 3, 1876, p. 28.
[c] Min. Proc. Inst. Civil Eng., vol. 45, 1876, pp. 59-60; vol. 105, 1891, pp. 35-46; The Rothamsted Experiments: Results and Summary Tables, 1903, p. 1.

Of these the Lawes and Gilbert results are perhaps of the greatest value, because they more nearly represent the normal conditions, and they extend through a sufficiently long period to obliterate temporary variations. While the quantitative values obtained from these experiments differ, the qualitative results, as shown by fig. 12, are essentially the same. All except the bare sand give curves of the same character as those obtained from the actual observation of ground-water fluctuations. The low percentage of water which passes through the soil in summer is emphasized by all, as is also the greater contribution during the winter months. Even in the bare sand, where the water sinks at once and so loses little by evaporation, a downward tendency of the curve during the summer months is evident. The effect of the heavy precipitation in the fall is particularly evident in the Lawes and Gilbert results (fig. 12), where it clearly hastened the time of occurrence of the maximum ground-water percolation by about two months.

EFFECT OF DEPTH OF SOIL ABOVE ZONE OF COMPLETE SATURATION ON TIME OF OCCURRENCE OF YEARLY MAXIMUM AND MINIMUM OF GROUND-WATER LEVEL.

It has been suggested that the soil above the ground-water table tends to destroy the effect of single rains by causing the water to be delivered gradually to the zone of complete saturation, whose upper surface is the water table. In the case of the English experiments at Rothamsted (Lawes and Gilbert) and Hemel Hempstead (Dickinson and Evans) the maximum percolation occurs from November to January, yet the water in the wells in that region, while commencing to rise about December, did not reach its maximum elevation until March,[a] a delay of about three months. Yet in any attempt to calculate the rate of percolation from these data two difficulties are encountered. In the first place the yearly maximum occurred at about the same time in this region in wells of all depths, and, furthermore, the Rothamsted results (fig. 12) show no very important difference in the time in which the water is discharged through 20, 40, and 60 inches of soil so far as it relates to the time of occurrence of the yearly maximum. In the second place the underground water is in motion, a certain amount is discharged at all times, and the amount increases with the head. The case is not, therefore, the simple one where water is caught in a measuring tube, as in the percolation experiments above described, but the water must reach the ground-water table at a rate greater than the rate of the outflow, else no rise will take place.

At Wiener Neustadt, Austria, a similar relation has been demonstrated by the observations made between 1883 and 1895, in connection with the Wiener Neustadt deep-well project for the supply of Vienna.[b] These wells are in a valley filling of fluvio-glacial material, somewhat irregular in character, which Suess describes as a series of old deltas.[c] The wells extend from Fisha River, a spring-fed stream, southwesterly along the Southern Railway. The land and the ground-water table beneath both rise gradually in this direction, but while the water table is at the surface of the ground at Fisha River, 6½ miles south, at St. Agyden, it is from 140 to 170 feet from the surface, the exact depth depending on the time of year. (See section at top of Pl. IX.) The curves obtained from this series of wells, extending roughly at right angles to the slope of the water plane, are entirely concentric, and the maximum and minimum occur at the same time, irrespective of depth of soil above the ground-water table. It would seem to follow from these data that no very satisfactory determination of the rate of downward percolation can be made from the relation of the time of greatest precipitation, or percolation, to the time of maximum

[a] Clutterbuck, James, Min. Proc. Inst. Civil Eng., vol. 2, 1842, p. 156.
[b] Bericht des Ausschusses für die Wasserversorgung Wiens: Österreichischer Ingenieur- und Architekten-Verein, 1895.
[c] Ibid., p. 32; see also Bericht über die Erfolge der Wiener Wasserleitungs-Commission, 1864; Karrer, F., Geologie der Franz Josephs-Quellenleitung: Abhandlungen der K.-k. geologischen Reichsanstalt, 1877.

ground-water level. The rise of the water is not determined by the simple delivery of water to the zone of complete saturation, but by the relation of the water so delivered to the rate of outflow. If the water is lowering, a certain amount is consumed in checking that tendency, and only the excess over the outflow is available for raising the ground-water level. Moreover, in several carefully observed instances, the depth of the soil above the ground water has been shown to have no effect on the time of occurrence of the yearly maximum.

The short-period observations on Long Island, New York, during the summer of 1903, however, gave quite different results from those obtained at Wiener Neustadt. The conditions do not appear to be essentially different; the glacial sands and gravels of the south plain of Long Island slope gradually to the ocean and in a similar way the valley glacial gravels of Wiener Neustadt slope to Fisha River, and there is apparently no great difference in the irregularity and complexity of the bedding. The Wiener Neustadt or Steinfeld Valley, it is true, is traversed by a large river, the Leitha, whose stages depend on the conditions affecting its headwaters in the mountains, but observations have shown that this stream, because of the silted character of its bed, affects only a few wells in its immediate vicinity, and is not to be regarded as a disturbing factor. (Compare the river stages with well curves on Pl. IX.) On Long Island the measurements in charge of Mr. Walter E. Spear, department engineer of the commission on additional water supply,[a] showed that, during the summer of 1903, the highest stage of the ground water occurred, as a rule, earlier in the shallow than in the deeper wells (fig. 13). Where the water level was less than 20 feet from the surface the highest stage of the ground water occurred in April, while where the water level was 60 to 75 feet below the surface it did not occur until August. The increase of the retardation was not always uniform. Thus the highest water in a 35-foot well near Jamaica (No. 551) occurred in May, while in a well of the same depth near Deer Park (No. 388) it did not occur until August, although in a well near Hicksville (No. 237), of about the same depth, the maximum occurred in May. Whether this irregularity is typical or is only a result of the rather peculiar season in which the measurements were made could be determined only by observations covering a period of years, instead of months. It should, however, be stated in this connection that along the south shore, where the Brooklyn water department has observed shallow wells for several years, the curve for 1903 is not greatly different from that of preceding years, indicating, so far as the shallow wells are concerned, that the year is not to be regarded as an abnormal one (fig. 15, p. 39). On the other hand, the results are so at variance with the thirteen years' observations at Wiener Neustadt, which apparently cover similar conditions, that further confirmation of these Long Island results, by additional observations, is needed before any conclusions can be drawn. Certainly the Wiener Neustadt data indicate that the depth of the soil above the ground-water table is of no importance in determining the time of occurrence of the maximum ground-water level. On the other hand, the Long Island observations suggest that a difference in thickness of 60 feet may delay the time of the occurrence of the maximum level four months.

The curves showing the result of the Long Island work indicate further that, in the soil in question, single showers frequently produce very definite effects in shallow wells, and that such effects become less as the depth of unsaturated material above the water table increases. Indeed, in the wells where the water is 30 or 40 feet below the ground, the curves are relatively smooth or the variations bear no evident relation to the rainfall.[b] Spear has attempted to trace the time of rise, due to given showers, from the shallow through the deeper wells, and so determine the rate of

[a] Long Island sources: Rept. New York City Commission on Additional Water Supply, 1904, appendix 7, Pl. IV, incorrectly numbered Pl. VI, p. 792.

[b] Many of the wells observed by the commission were open, dug wells, which were in use, and the minor fluctuations are partially due to this cause, as well as to barometric and thermometric changes.

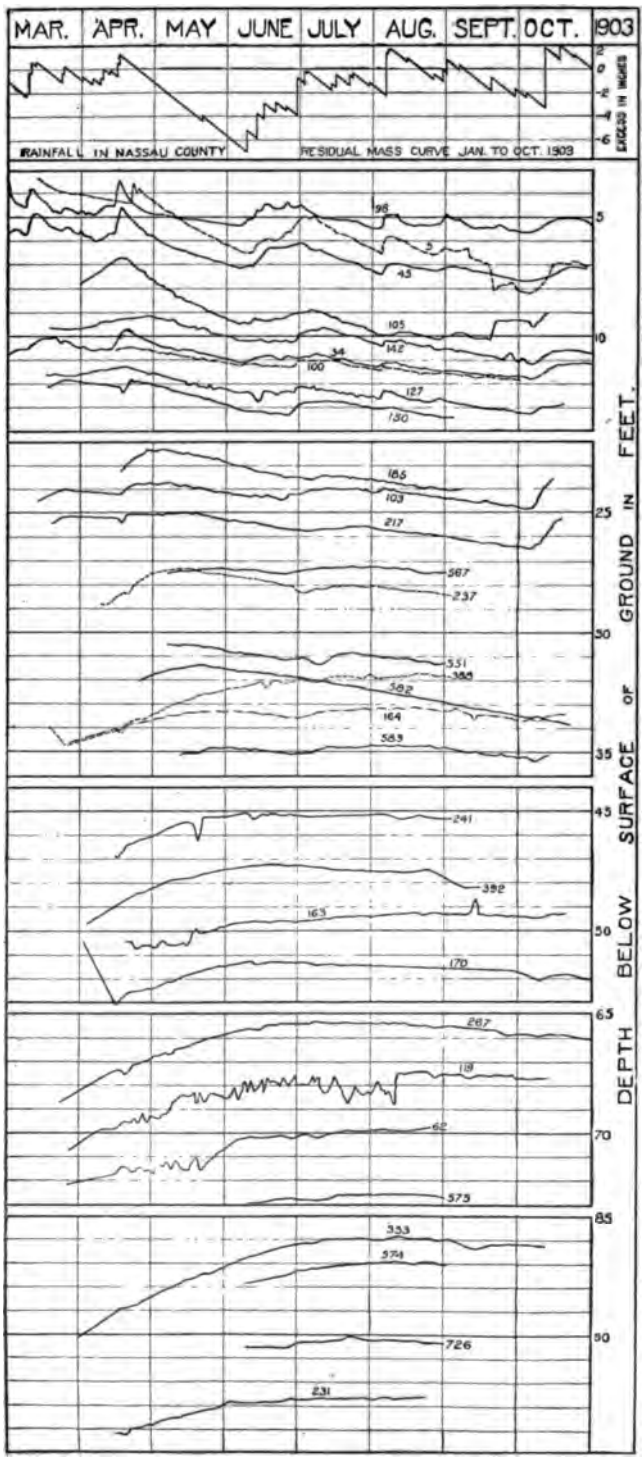


FIG 13.—Fluctuations of water level in wells on Long Island, New York, based on observations at intervals of one to three days by the Long Island division of the New York City commission on additional water supply. (After Spear, 1904.) The location of the wells is given in Pl. I. The numbers are the same as those used in the commission's report.

downward percolation or downward capillary flow. There are certain difficulties in the way of determining the value sought in this manner. In the first place, the fluctuations in the shallow wells can not be satisfactorily correlated with those in the deep ones, and the only line which can be followed through the diagram prepared by Spear is the time of maximum ground water, which, as indicated above, in this region during the time of observation, in general lags proportionally to the depth. This gives a fairly regular curve and the remaining curves have been inferred on either side of this one. The yearly maximum, however, can scarcely be attributed to a single rain, but represents rather the culmination of a whole series of events, and hence can not be used as a basis of such a calculation.

In the case of regions like Wiener Neustadt it is clear that the results from calculations of this character would have no meaning, and, indeed, what do the values really represent on Long Island?

IRREGULAR SECULAR FLUCTUATIONS.

The observations of Dickinson and Evans and of Lawes and Gilbert with percolation gages developed the fact that, as a rule, not only did more water percolate in wet than in dry years, but that the percentage of rain water which passed through the soil columns was usually much greater in wet years than in dry ones. Thus while the average yearly percolation of 1870–1902 at Rothamsted (Lawes and Gilbert) was 49 per cent of the yearly rainfall of 28 inches, in the year 1878–79, when 40.2 inches of rain fell, 61 per cent of the rain water passed through a soil column 60 inches high, and in the year 1877–78, with a rainfall of 18.2 inches, the percolation was but 36 per cent (see p. 47.) The general tendency—although there are exceptional cases, such as recorded at Hemel Hempstead (Dickinson and Evans) in 1858–59, when, with a rainfall of 28 inches, 2 inches more than the annual average, the percolation was but one-third of 1 per cent instead of the usual 27 per cent—is for the small differences in the annual rainfall to have a rather magnified value in the ground-water fluctuations.

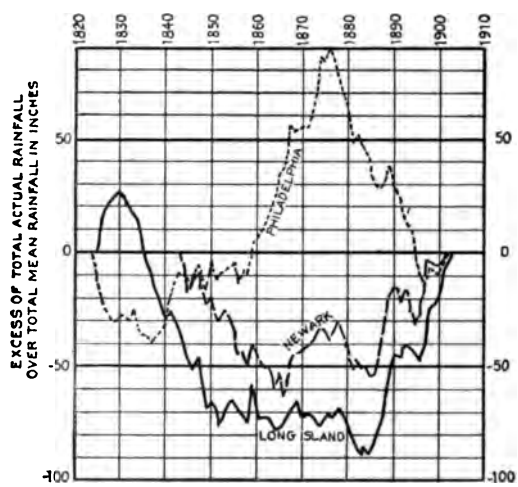


FIG. 14.—Residual-mass curves of rainfall for Long Island, N.Y., Newark, N. J., and Philadelphia, Pa. (After Spear, 1904.) These curves show the cumulative excess or deficiency of the total actual rainfall over the total mean rainfall for the periods under consideration, and as these excess or deficiency values are those which determine the long-period rise and fall of the ground water they indicate the general character of the secular fluctuation of the ground water occurring at these points.

The yearly variations of the rainfall are generally progressive over rather long periods (fig. 14), and corresponding broad, irregular variations of the ground-water level are produced. On Long Island the shallow wells observed by the Brooklyn waterworks show, besides the annual fluctuations, secular variations corresponding in general with those of the rainfall (fig. 15). Thus the lowest point in both curves is in 1901 and the highest in 1899. Many differences are, however, to be noted between the two curves. The annual curve, though it may be slightly modified, persistently recurs, whatever the rainfall. Note in this connection the regular downward course of the ground water in the latter part of

1898 and 1903, when the rainfall curve is rising, and the appearance in 1900 of a typical yearly curve when the rainfall curve falls rather regularly from the spring of 1899 to 1901.

Similarly, in the Wiener Neustadt observations (Pl. IX, p. 62) the secular variations of the ground-water level broadly follow the variations of the rainfall.

The observations of Auchincloss[a] on a well at Bryn Mawr, Pa., which have been plotted by Spear[b] in connection with the yearly rainfall and temperature curves, likewise show pronounced annual and secular fluctuations. Here, however, the secular fluctuations of the ground water, while broadly resembling the rainfall variations, show some points of difference. Thus, the minimum of the secular curve of the ground water is in 1885–86, while the minimum rainfall is in 1887, and the general shape of the two curves for 1886–87 and 1888 is by no means parallel. The positions of the maxima, however, agree closely, and there is a general falling off in both curves from 1889 to 1893–94. Though the extreme rains of the latter part of 1889 temporarily obliterated the annual curve, it quickly reasserted itself.

In general it may be said that irregularities in the yearly curve are due to irregularities in the rainfall occurring in the same year.

AMOUNT OF ANNUAL AND SECULAR FLUCTUATION.

The size of the annual fluctuations depends principally upon (1) the percentage of rainfall reaching the ground water; (2) the amount of free pore space of the strata in the zone affected by the fluctuations, and (3) the relation of the ground-water table to the topography of the region involved.

It is relatively self-evident that, where a single well is considered, the range of the yearly fluctuations will vary with the first factor, and that in general the same amount of infiltration will produce a greater fluctuation where the pore space is small than where it is large. It does not, however, follow that in a given region, in beds of the same porosity, the same annual rainfall under the same climatic conditions will produce the same results. Observations have shown that whatever the rainfall or porosity, provided the latter be reasonably constant in the area under consideration, the annual fluctuations approach zero at the point of discharge and tend to regularly increase in magnitude from that point to the ground-water divide.[c] Thus at Wiener Neustadt (Pl. IX, p. 62), near the ground-water discharge into Fisha River, where the depth to the ground-water table is about 5 feet, the yearly fluctuation is 3 to 4 feet, while at St. Agyden station, where the water plane is about 150 feet from the surface, the fluctuation is 25 to 30 feet, and the fluctuations in the intervening wells are proportional to their position between these two points. On Long Island the annual fluctuation 2 miles from the shore, at Millburn (figs. 13, 15), is 22 inches, while at the ground-water divide, 8 to 9 miles from the south shore, the fluctuation is about 10 feet. A few observations regarding the amount of the yearly fluctuation at different points have been collected in the table following. Many of these points of observation are located near the points of discharge, and the values as a whole are to be regarded as low.

In records for but a few years it is evidently impossible to separate the annual from the secular fluctuations. When, however, the observations cover a considerable period, it is possible to obtain a value for the secular fluctuation. This equals the total range less the average yearly fluctuation. A few such values are given in the table on page 40.

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[a] Auchincloss, W. S., Waters within the Earth and Laws of Rainflow, Philadelphia, 1897, p. 9.

[b] Spear, Walter E., Rept. Commission on Additional Water Supply for the City of New York, 1904, appendix 7, fig. 45, p. 822.

[c] The cross section from Watford to the Chiltern Hills midway between Colne and Gade rivers, which accompanies Clutterbuck's discussion of the "Periodic Alternations of the Chalk Water Level under London" (Min. Proc. Inst. Civil Eng., vol. 9, 1850, Pl. VI), is a most excellent diagrammatic illustration of this principle.

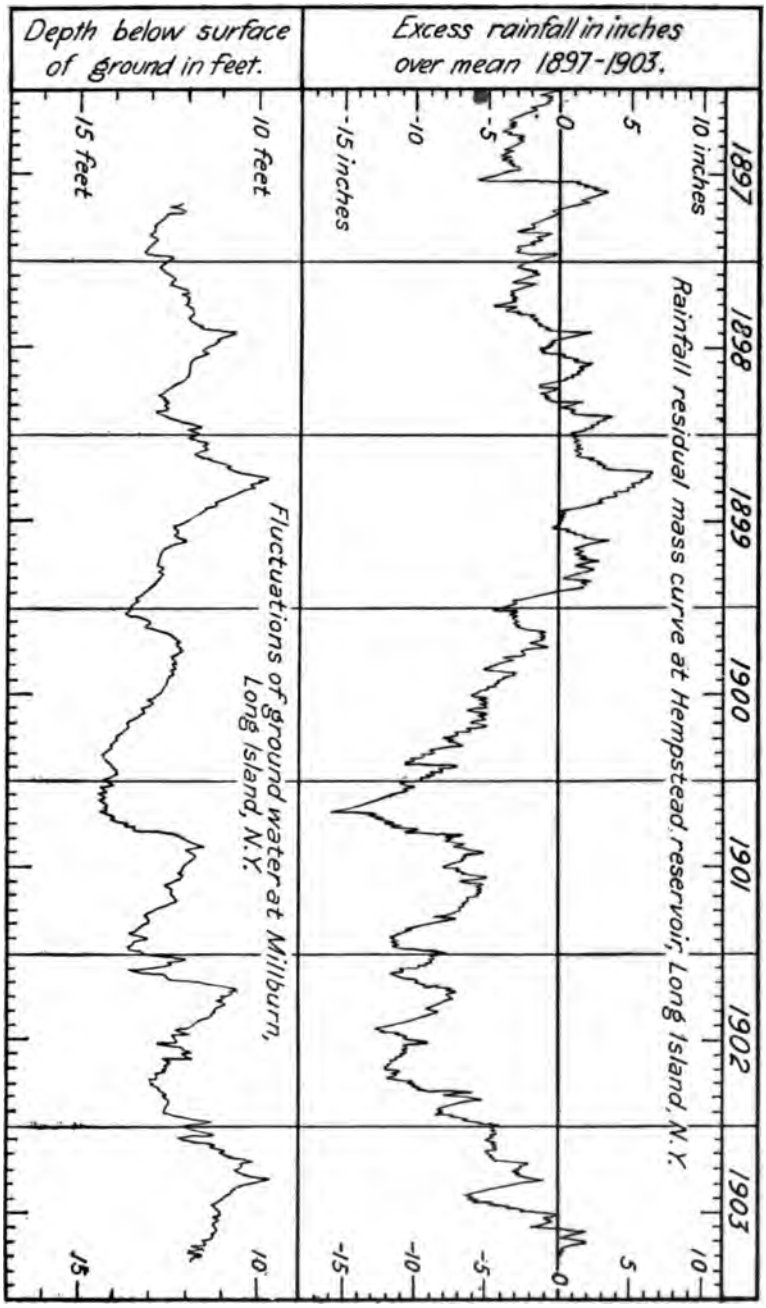

FIG. 15.—Annual and secular changes of the ground-water level and fluctuations due to single showers in a shallow well at Millburn, N. Y., from the observations of the Brooklyn water department. (After Spear, 1904.)

Table giving amount of annual and secular fluctuations of water in wells.

Location.	Average annual rainfall.	Character of water-bearing strata.	Distance from point of ground-water discharge.	Total depth of well.	Distance of mean high water from surface.	Average annual fluctuation.	Secular variation for period given.[a]	Period of observation.	Observer.
UNITED STATES.	*Inches.*		*Miles.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*		
Millburn, Long Island, N.Y.	44	Sand and gravel	0.02	25	10	1.8		1897–1903	Brooklyn waterworks.[b]
Hicksville, Long Island, N. Y.	44	do	7.0	100	80	10.0		1903	Estimated from observations of New York commission on additional water supply.[c]
Ann Arbor, Mich.		Glacial drift				2.3	6.7	1885–1901	Michigan State board of health.[d]
Michigan wells (average of 18)	35	do		8–55		2.6		1878–1897	Do.
Lansing, Mich.	30	do		27	25	.6	3.7	1885–1901	Do.
Bryn Mawr, Pa.	49	Decomposed mica schist.	.25	65	43	5.3	13.7	1886–1895	Auchincloss.[e]
Geneva, N. Y.	28	Glacial drift		40	5	9.7		1887–1889	Emery.[f]
MIDDLE EUROPE.									
Munich (average of 2 wells)	32	Gravel		18	18	.9	4.5	1856–1885	V. Pettenkofer.[g]
Berlin (average of 37 wells)	23	Alluvium and glacial deposits (sand).		Shallow		1.8		1870–1885	[Soyka.][h]
Salzburg	46			19		.7	2.7	1860–1885	Spangler.[i]
Do	46			26		4.0		1876–1880	Liznar.[k]
Graz	35			19		3.0		1876–1880	Do.
Innsbruck	33	Sand and gravel		32		7.5		1876–1880	Do.
Trieste	51	do		18		7.3		1876–1880	Do.
Klagenfurt	42					3.4		1877–1886	Do.
Do	42			30		2.6		1877–1886	Do.
Frankfurt a. M. (average of 6 wells)	25	Diluvium		25–50	16–30	1.2		1869–1885	[Soyka.][l]
Bremen	26					1.9		1872–1884	Liznar.[l]
Brünn	22					1.9		1865–1880	[Soyka.][l]
Prag	19			26	17	1.4		1876–1880	Do.
Krakau	25			20	11	4.7		1876–1880	Do.
Josephstadt	24			73	33	8.2		1876–1880	Do.

Baden				17	13	.8		1876–1880	Do.
Agram	35			32	16	8.4		1876–1880	Do.
Debreczin	25			21	11	1.8		1876–1880	Do.
Szegedin	21			19	8	1.9		1876–1880	Do.
Czernowitz	26			209	154	2.0		1876–1880	Do.
Wiener Neustadt	25	Sand, gravel, and conglomerate.	.3	8	3	2.6	3.6	1886–1890	Bericht des Ausschusses für die Wasserversorgung Wiens.
Do	25	do	2.7	71	44	14.9	9.6	1886–1890	Do.
Do	25	do	6.8	177	144	24.4	21.5	1886–1890	Do.
ENGLAND.									
Sussex, Alfriston	30	Chalk	.2	16	7	2.0		1885–1899	Whitley.[m]
Sussex, Jevington	30	do	2.5	198	120	75.0		1885–1899	Do.
Sussex, Eastdean	27	do	1.5	163	154	10.0		1885–1899	Do.
Hertfordshire	30	do				70.0			Evans.[n]
Hertfordshire (average)	30	do				20.0–30.0			Clutterbuck.
Southern England	30	do				2.0–135.0		1841–1851	Lucas.[o]
London		do				4.6		1841–1848	Clutterbuck.[p]
Chelgrove		do				[q]135.0		1841–1851	Lucas.[r]
Caterham		do				[q]100.0			Lucas.[s]
Cheshire, Anderton		New red sandstone?		225	75	93.0		1855	Northcote.[t]

[a] Maximum range for period given less the average yearly fluctuation.
[b] Rept. New York City Commission on Additional Water Supply, 1904, appendix 7, Pl. IX.
[c] Ibid., Pl. VI (should be IV), pp. 819–820.
[d] Ann. Repts. Michigan State Board of Health, 1879, 1881–1902.
[e] Auchincloss, W. S., Waters within the Earth and Laws of Rainflow, 1897, p. 9.
[f] Emery, Frank E., Sixth, Seventh, and Eighth Ann. Repts. New York Expt. Station, 1888–1890.
[g] Soyka, Schwankungen des Grundwassers: Penck's Geographische Abhandlungen, 1888, pp. 31–32.
[h] Ibid., p. 34.
[i] Ibid., pp. 37–38.
[k] Ibid., pp. 41–42.
[l] Ibid., pp. 48–51.
[m] Whitley, Henry Mitchell, Min. Proc. Inst. Civil Eng., vol. 142, 1900. pp. 342–351.
[n] Evans, Sir John, Min. Proc. Inst. Civil Eng., vol. 45, 1877, p. 124.
[o] Lucas, Joseph, Min. Proc. Inst. Civil Eng., vol. 47, 1877, pp. 70–167.
[p] Clutterbuck, Rev. James, Min. Proc. Inst. Civil Eng., vol. 9, 1850, p. 153.
[q] Extreme range for period given: it therefore includes secular as well as annual variations.
[r] Min. Proc. Inst. Civil Eng., vol. 47, 1876–77, pt. 1. 1877, p. 87.
[s] Ibid., p. 118.
[t] Northcote, A. B., Phil. Mag., 4th ser., vol. 14, 1857, p. 471.

FLUCTUATIONS DUE TO SINGLE SHOWERS.

In the foregoing consideration of the relation of the rainfall to secular and annual fluctuations, the most important factor was clearly the amount of water actually contributed to the zone of complete saturation, or the ground water.[a] In these cases the water table rises or falls because the amount of water received is greater or less than the outflow.

In the consideration of single showers, however, it is found that another factor is of as great or even greater importance. Single showers may affect the water level in a well in two ways: (1) By transmission of pressure without any actual addition to the ground water—indeed, in many cases the elevation of the water in the well is accompanied by an actual depression of the ground-water table; (2) by an actual contribution to the ground water whereby the level of the water table is raised.

FLUCTUATIONS PRODUCED BY SHOWERS BY TRANSMITTED PRESSURE WITHOUT ANY INCREASE IN THE GROUND WATER.

King observed at Madison, Wis.,[b] that the water often rose in wells very suddenly and sharply during summer rains, when an investigation of the soil showed that it was dry beneath the surface covering wet by the showers. Similar occurrences were recorded at Lynbrook, N. Y., where in a 2-inch well 14 feet deep every rain—during the period of observation, July 17 to September 10—was recorded and its duration and complexity indicated. Many of these fluctuations produce no permanent deflection of the ground-water curve and the evidence that no water from several of these rains reached the ground water is regarded as conclusive (Pl. VI; also note particularly the behavior of the shallow well August 19–21 and the fluctuations produced by rains of July 20, 22, 30, and August 6; the two successive showers of August 6–7 are particularly noteworthy).

In the case of wells which are not separated from the main water table by impervious layers and in which the water is not under artesian pressure, this is due largely to the hydrostatic transmission of pressure by means of the soil air. When the rain strikes the surface it closes the superficial soil pores or interstices and thus confined and compresses the air in the soil between the surface and the ground-water table. The weight of the rain is thus transmitted to the ground-water table, and the extra head so developed raises the water in wells and increases the discharge at the ground-water outlets. The effect on the stream flow is very analogous to the increase produced by a lowering of the barometric pressure. It is thus possible for a rain to produce instantly a change in the water level in wells and an increase in the ground-water outflow without contributing a drop to the ground water. This has an important bearing on the calculation of "flood flows" from ground-water-fed streams, for it is evident that in this manner a decided rise in the stream may be produced by a rain from which there is no direct run-off and which does not reach the ground-water table.

Two other factors may be involved in the production of the change in level during rains: (1) An actual elastic compression or plastic deformation of the soil, and (2) a change in the capillary conditions. King observed in a shallow well near a railroad track that the passage of a freight train caused a quick rise and fall of the water in the well (p. 75). Apparently the weight of the train compressed the earth and by decreasing the pore space caused the water to rise. The weight of the rain might have a similar effect. Under this hypothesis the water would rise on the addition of the rain and gradually fall on its removal by evaporation.

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[a] Ground water as here used does not include the hygroscopic and capillary water above the water table, or zone of complete saturation. For the purpose of this discussion, water is not considered "ground water" until it reaches the water table.

[b] Bull. U. S. Weather Bureau No. 5, 1892, pp. 20, 72–73.

Regarding the second hypothesis it is well known that changes in the surface conditions greatly affect the capillary action of the soil. At Purdue University it was found that the addition of a thin layer of soil to the surface of a lysimeter caused an immediate discharge of water.[a] This was attributed to a change in the capillary conditions, and it has been suggested that the wetting of the ground surface would produce a similar effect. King, however, observed [b] that a moderate wetting of the surface tended to increase the upward percolation, and the effect of wetting the surface at Lynbrook would therefore be to diminish rather than increase the rise due to rains which do not contribute to the ground water.

At the Colorado experiment station Headden has observed [c] that light rains during dry periods produce a comparatively great increase in the height of the water plane, while in intervals of abundant moisture, when the soil is wet, rains of this character do not produce such an increase; moderate rains are here sometimes accompanied by temporary depressions of the water plane. These observations may be explained on the basis that the soil air is the principal factor and that when the soil is very moist there is so little soil air that no effect is possible with slight showers. The cause of the temporary depression after moderate rains is not evident unless the conditions are unfavorable for the transmission of pressure by the soil air, but are such that the increased upward capillary action resulting from the moistening of the surface is sufficient to perceptibly decrease the ground water.

Where there is an impervious layer between the water-bearing strata and the local ground-water surface, and where there is artesian pressure, the added weight due to the rainfall in all cases acts directly. In case the rain is uniform over a considerable area this pressure may be regarded as acting on an elastic body and the same character of results is to be expected in both deep and shallow wells. Thus in the Lynbrook wells on July 22 and August 25 all wells show a sharp vertical rise (Pl. VI). On July 22 the rise started in the 14-foot well at 10 p. m., in the 72-foot well at 10.25, and in the 504-foot well at 10.34; on August 25 a somewhat similar lag is noted, the 14-foot well rising at 4.10 p. m., the 72-foot well at 4.20, and the 504-foot well at 4.24. The cause of this lag is not fully apparent. With a direct transmission of pressure such as the curve indicates no lag is to be expected. It may be that in this case the soil is to be regarded as having some of the plastic characters shown in other cases.

On the other hand, when the rainfall is unequally distributed in time and amount a plastic deformation may result, due to unequal loading, which will give rise to different results in wells of different depths. In the shallow well the zone of influence is relatively limited and the condition in this area may be regarded as fairly uniform. The result is therefore immediate and abrupt, as in the first case. In the deeper wells, however, the increasing zones of influence bring in more factors, which, arriving progressively from different sources, tend to produce a more and more gradual change. Thus, in the Lynbrook wells there were on August 6–7, 11, and 20 abrupt changes in the 14-foot well and a more gradual one in the 72- and 504-foot wells.

This plastic deformation in the surficial beds, produced by varying load and the response of the water to it, throws some light on the extreme complexity of the fluctuation recorded in the wells, for it suggests that variation in load, from whatever cause, will produce corresponding fluctuations. The water level in deep wells where an artesian head is developed may thus be very sensitive to local conditions, the effect of local rainfall and of the yearly fluctuations of the local ground-water level being felt to a greater or less degree by transmitted pressure in the deeper zones.

[a] Second Ann. Rept. Indiana Expt. Station, 1889–90, pp. 32–33.
[b] Seventh Ann. Rept. Wisconsin Agric. Expt. Station, 1890, p. 135.
[c] Headden, William P., A soil study, pt. 4, The ground water: Bull. Colorado Agric. Expt. Station No. 72, 1902.

FLUCTUATION OF THE GROUND-WATER LEVEL RESULTING FROM SINGLE SHOWERS, BY ACTUAL PERCOLATION.

The fluctuations produced by direct percolation are of a much less abrupt character than those just described; indeed, it is usually the case that the water is delivered so gradually to the water table that no change is noticed. Only in the shallow wells in coarse material can these fluctuations be identified, except in the cases of extraordinary rains, when the result is an irregularity of greater or less importance on the regular annual ground-water curve.

On Long Island the shallow wells near the south shore are affected by most of the important rains, although part of the fluctuations recorded are of the character just described. (See figs. 13, 15.) This is due to the coarseness of the surficial material and to the nearness of the water table to the surface. In the wells in which the ground water is farther from the surface the effect of any rain can not be positively identified. In the Wiener Neustadt records the effect of single rains is entirely obliterated (Pl. IX), and in long observations of the chalk waters of England the general rule, to which, of course, there are exceptions where large underground caverns are concerned, is that the water is delivered very gradually to the ground-water table.

PERCENTAGE OF RAINFALL CONTRIBUTED TO THE GROUND WATER.

METHODS OF ESTIMATION.

In connection with this discussion of the fluctuation of the water level it may not be inappropriate to take up the allied question, to which reference has been made at several points, of the percentage of rain contributed to the ground water.

Estimates of this character have been made by three methods—(1) by means of the lysimeter, (2) by stream discharge, and (3) by changes in the level of the ground water.

ESTIMATION OF PERCOLATION BY MEANS OF LYSIMETERS.

By the lysimeter method the rain water passing through a column of soil in field conditions is measured directly. The gage used for this purpose consists of a vessel with impervious sides and a pervious bottom, filled with the soil to be tested, and buried so that the surface of the soil in the gage is at the same level as the surrounding ground. The discharge through the pervious bottom of the vessel is collected by a cone and conducted by a small tube to the measuring gages. In the early forms of the apparatus used by Dalton, 1796, and Dickinson, 1835, surface outlets were provided to discharge the excess rainfall, but these were abandoned when it was found that on the level surface of the gage there was no surface run-off.

Many observations have been made along this line, and while the results for long periods clearly have a greater value than those for short periods, some of these short-period values have been included in the table on the following page for the purposes of comparison.

Lysimeter results have been subjected to considerable criticism, and very differing views expressed regarding their value. It has been suggested (1) that the material in the gage is not in the natural condition of consolidation, and that, therefore, the results are too high; (2) that the underdrainage necessary to collect and carry the water from the base of the soil column to the measuring tube introduces an unnatural condition whereby the results are too low; (3) that the surface run-off factor is surpressed and the results are too high.

Observer.	Locality.	Conditions of experiments.	Period.	Length in years.	Rainfall.	Percolation	Per cent of rainfall.
					Inches in depth.	*Inches in depth.*	
Dalton[a]	Manchester, England	Cylinder 10 inches in diameter, 3 feet deep, filled with average Lancashire soil[b] and sunk level with ground; after first year covered with grass.	1796–1798	3	33.6	[c] 8.4	[c] 25.0
Maurice[d]	Geneva, Switzerland	Cylindrical iron vessel filled with soil	1796–1797	2	26.0	10.2	39.0
Gasparin[e]	Orange, southern France	do	1821–1822	2	28.0	7.0	20.0
Dickinson and Evans[f]	Nash (or Apsley Mills), Hemel Hempstead, Herts, England.	Gage sunk flush with ground, filled with soil 10 inches, sandy gravel 15 inches, clean coarse gravel 11 inches,[g] representing ordinary surface conditions of that region. From 1835 to 1858 gage consisted of a wooden cylinder 12 inches in diameter and 3 feet deep, with lead funnel and draw pipe at bottom. After 1853 a cast-iron cylinder, 18 inches in diameter and 3 feet high, was used. Surface in all cases covered with grass.	[h] Oct., 1835–Oct., 1884	[h] 49	28.0	7.5	26.8
Do	do	Wooden cylinder 12 inches in diameter, 3 feet deep, filled as above.	Oct., 1835–Oct., 1853	18	26.6	9.2	34.6
Do	do	Cast-iron cylinder 18 inches in diameter, 3 feet deep, filled as above.	Oct., 1853–Oct., 1875	22	25.7	5.6	21.7
Do	do	Cast-iron cylinder. Minimum yearly percolation of period 1835–1875.	Oct., 1858–Oct., 1859	1	27.95	.9	.3
Do	do	Cast-iron cylinder. Maximum yearly percolation of period 1835–1875.	Oct., 1859–Oct., 1860	1	36.9	12.4	33.6
Do	do	Cast-iron cylinder. Minimum yearly rainfall of period 1835–1875.	Oct., 1863–Oct., 1864	1	17.66	3.53	20.0
Do	do	Cast-iron cylinder	Oct., 1873–Oct., 1874	1	19.62	1.91	9.7

[a] Mem. Lit. Phil. Soc. Manchester, vol. 5, 1st ser., p. 360; Jour. Royal Agric. Soc., vol. 10, 1844.
[b] Described by Prestwich (On Water-bearing Strata about London, 1899, p. 111) as common soil of the new red sandstone area which contains a good deal of clay.
[c] Field has suggested (Min. Proc. Inst. Civil Eng., vol. 40, 1876, p. 88) that the underdrainage of Dalton's gage was very imperfect, and that this result is perhaps too low.
[d] Bibl. Universelle de Genève, Sciences et Arts, vol. 1; Gilbert, J. H., Min. Proc. Inst. Civil Eng., vol. 45, 1876, p. 56.
[e] Cours d'Agriculture, vol. 2, p. 116.
[f] Dickinson, John, and Evans, John, Min. Proc. Inst. Civil Eng. [vol. 2], 1843, pp. 160–161; vol. 9, 1850, p. 158; vol. 20, 1861, pp. 219–222; vol. 45, 1876, pp. 208–216.
[g] Min. Proc. Inst. Civil Eng., vol. 14, 1855, pp. 86–87.
[h] Obtained by combination of values given in Min. Proc. Inst. Civil Eng., vol. 105, 1891, p. 50, and vol. 20, 1861, p. 220.

Results of lysimeter experiments to determine the amount of rainfall reaching the ground water—Continued.

Observer.	Locality.	Conditions of experiments.	Period.	Length in years.	Rainfall.	Percolation.	Per cent of rainfall.
					Inches in depth.	*Inches in depth.*	
Dickinson and Evans	Nash (or Apsley Mills) Hemel Hempstead, Herts, England.	Cast-iron cylinder 18 inches in diameter, 3 feet deep, filled with broken chalk covered with a thin layer of soil and grass.	Oct., 1853–Oct., 1875	22	25.7	9.1	35.4
Charnock[a]	Ferrybridge, Yorkshire, England.	"Into a leaden vessel 1 foot square and 3 feet deep with drain at bottom was put 2 feet of gravel and the remainder filled with the average quality of magnesium-limestone soil." The soil was kept free from weeds and well stirred.	1842–1846	5	24.6	4.8	19.6
Greaves[b]	Lee Bridge, near London, England.	Slate box 3 feet square, sunk in ground and filled with loam, gravel, and sand, all well mixed beforehand, trodden in and turfed. Material intended to represent common Hertfordshire land.	1852–1873	22	25.84	6.87	26.4
Do	do	Slate box, filled as above. Year of minimum percolation, period 1853–1873.	1854	1	17.5	1.25	7.1
Do	do	Slate box, filled as above. Year of minimum rainfall, period 1853–1873.	1864	1	15.9	3.8	24.0
Do	do	Slate box, filled as above. Year of maximum percolation, period 1853–1873.	1866	1	31.7	12.6	39.7
Do	do	Slate box, filled as above. Year of maximum rainfall, period 1853–1873.	1872	1	37.2	12.0	32.2
Do	do	Slate box, filled with fine sand, kept free from vegetation.	1860–1873	14	25.7	21.4	83.3
Von Möllendorff[c]	Görlitz, Silesia, Germany	Cylinder 1.25 meters deep, filled with clay, not covered with vegetation.	1853–1856	4	25.6	7.2	28.1
Do	do	Cylinder 1.25 meters deep, filled with loam, not covered with vegetation.	1853–1856	4	25.6	10.5	41.0
Do	do	Cylinder 1.25 meters deep, filled with sandy loam, not covered with vegetation.	1853–1856	4	25.6	10.4	40.5
Do	Tharoud, Saxony, Germany.	Calculated on discharge drain placed at a depth of 1.25 meters in a field covered with vegetation; clay soil.	1853–1856	4	28.8	11.7	40.8
Do	do	Calculated on discharge drain placed at a depth of 1.25 meters in a field covered with vegetation; loamy soil.	1853–1856	4	28.8	16.9	58.7
Risler[d]	Calèves, near Nyon, Switzerland.	By gaging drains 1.2 meters deep; compact, impervious subsoil; land cropped as usual during experiment.	1867–1868	2	41.0	12.3	30.0

Wollny[e]	Munich, Bavaria	Gage 1.20 meters deep, filled with sand, not covered with vegetation.					
Do	do	Gage 1.20 meters deep, filled with loam, not covered with vegetation.	1878–1880	3	42.3	11.2	26.5
Do	do	Gage 1.20 meters deep, filled with peat, not covered with vegetation.	1878–1880	3	42.3	19.0	44.9
Lawes and Gilbert[f]	Rothamsted, Hertfordshire, England.	Gage one-thousandth of an acre area, soil rather heavy loam with clay subsoil built in, in natural state of consolidation with brick and cement. No vegetation allowed to grow on gages, which are surrounded by meadow land; soil column 20 inches deep.	Sept., 1870–Sept., 1902	32	28.1	13.7	48.8
Do	do	Same as above; soil column 40 inches deep.	Sept., 1870–Sept., 1902	32	28.1	14.5	51.6
Do	do	Same as above; soil column 60 inches deep.	Sept., 1870–Sept., 1902	32	28.1	13.5	47.9
Do	do	Same as above; soil column 60 inches deep. Year of maximum rainfall, period 1870–1902.	Sept., 1878–Sept., 1879	1	40.2	24.4	60.7
Do	do	Same as above; soil column 60 inches deep. Year of minimum rainfall, period 1870–1902.	Sept., 1897–Sept., 1898	1	18.2	6.5	35.7

[a] Charnock, Chas. [Results of percolation experiments near Ferrybridge, York, 1842–1846]: Jour. Royal Agric. Soc., vol. 10, 1849, p. 516.
[b] Greaves, Chas., Min. Proc. Inst. Civil Eng., vol. 45, 1876, pp. 19–48.
[c] Von Möllendorff, G., Die Regenverhältnisse Deutschlands, Görlitz, 1862; Gerhardt, I. P., Der Wasserbau, Leipzig, 1892, p. 37.
[d] Archives des Sciences, Bibliothèque Universelle, Sept., 1869, quoted by Gilbert, Min. Proc. Inst. Civil Eng., vol. 45, 1876, p. 56, and Gerhardt, Der Wasserbau.
[e] Wollny, E., Forschungen a. d. Gebiete d. Agrikulturphysik; Gerhardt, Der Wasserbau, Leipzig, 1892, p. 37.
[f] Lawes, Sir John, and Gilbert, Sir J. H., Min. Proc. Inst. Civil Eng., vol. 45, 1876, pp. 59–60; id., vol. 105, 1891, pp. 35–46; The Rothamsted Experiments, Plans, and Summary Tables, 1903, p. 1.

The objection regarding consolidation is well taken, though it clearly does not apply to the results at Rothamsted, where natural soil columns were used, and where very high results were obtained, or to other gages after the first few years, during which the soil has settled. In the Hemel Hempstead experiments the percolation between 1835 and 1843 was 42.5 per cent of the rainfall, while in the period 1835 to 1853 it was but 35 per cent, a decrease which is perhaps due in part to the gradual compacting of the soil, though it is also affected by the varying rate of percolation, for it must be remembered that the amount of percolation depends more on the time at which the rain falls and the manner in which it is distributed than on the actual amount.

Regarding the unnatural condition introduced by the method of drainage, it has been suggested on the one hand that the lower part of the soil column is thus exposed to evaporation, and that not only is there a loss in this manner not accounted for by the measuring gage, but that the dry condition of the basal layer would retard the percolation to a measureable extent and increase the loss by evaporation from the surface of the ground. Ebermeyer has shown, however, that with small lysimeters the lower portion of the soil column is damper than normal,[a] and he proposed to remedy this by constructing larger gages. These defects are clearly ones of construction which it is possible to remedy. At Rothamsted essentially the same results were obtained from soil columns 20, 40, and 60 inches high (fig. 12), showing conclusively that in this case the natural conditions were not essentially disturbed.

Indeed, it is believed that carefully conducted lysimeter observations, extending over long periods, such as are represented by the Dickinson and Evans and the Lawes and Gilbert experiments, give very important values bearing on this question, the Lawes and Gilbert results being particularly important and trustworthy. They indicate that in the climatic condition of middle England, with 28 inches of rainfall, half of the rainfall is contributed to the ground water through a rather heavy soil not covered with vegetation, and half of it evaporated. If the rainfall is greater, the percentage increases, if less, it decreases. Had the ground been covered with leaves, straw, or similar matter the percolation would have been greater; if covered with growing vegetation, less. Lawes and Gilbert estimate, from their observations on plant transpiration, that in this region 2 inches per year would represent the plant transpiration in the area of downs and waste land, where there was very little vegetation, while with a heavy grass or mangel crop it would amount to 7 inches or more. The average for the whole region was estimated at 3 to 4 inches. This would make the percolation for soil of this character, in the case of downs and waste land, 43 per cent; for the average mid-England district, 39 per cent, and for land covered with heavy grass or mangel crop, 25 per cent or less.

It should be noted in this connection that while the most of these observations, including those at Rothamsted, were made in connection with agricultural investigations, the Hemel Hempstead and Lee Bridge (Greaves) experiments were made for engineering purposes. The Hemel Hempstead observations were undertaken by a paper manufacturer, dependent on the water power of a spring-fed stream. He argued that stream flow depended on the amount of water which percolated through the soil; that measurements of this quantity would indicate the stream flow to be expected during the following summer. It is stated that he found that the indications of the gage during the winter enabled him to calculate the supply of water from the stream during the ensuing season, that he had always found the indication perfectly reliable,[b] and that he was accustomed to regulate the volume of the orders accepted for the summer season by the indication of the gage for the preceding winter.[c] Clutterbuck adds, though the relation is clearly more of a qualitative than

[a] Reported by R. H. Scott, Jour. Royal Agric. Soc., 2d ser., vol. 17, 1881, pp. 66–67.
[b] Min. Proc. Inst. Civil Eng., vol. 2, 1842, p. 158.
[c] Ibid., p. 157.

a quantitative one, that the rise in level of the water in the wells in that region is found to coincide with the readings of the Dickinson gages.[a]

The lysimeter certainly furnishes a very direct and exact means of determining the amount of water contributed to the ground water at any given point. The principal objection to it is that the block of soil tested is not necessarily representative of the whole area under investigation.

Somewhat similar experiments, having for their object the determination of the evaporation from plants, have been conducted by many agriculturists in this country, notably by King,[b] by means of tanks which can be lifted from the ground and weighed. This method is not so applicable to the amount of water contributed to the ground water as is the lysimeter type used above, for the results are less direct, the percolation being inferred from the evaporation generally under more artificial conditions than with the lysimeter.

ESTIMATION OF PERCOLATION FROM THE STREAM DISCHARGE.

The favorite method of estimating the evaporation of a given drainage basin is to subtract the stream discharge expressed in inches of rainfall over the drainage basin from the average rainfall. Thus it is assumed that—

Rainfall — Stream discharge = Evaporation.

The stream discharge is composed of (1) the rain water which flows into the drainage channels without penetrating the soil—this is, strictly speaking, the run-off, but as this word is now by common consent used for the whole quantity of water discharged by the river, this contribution may be somewhat arbitrarily referred to as the flood flow; and (2) the water which after a greater or less journey through the earth returns to the surface—this may be called the spring or ground-water flow of the river. It has been assumed that the ground-water flow of a river is its low-water flow and that any excess of this quantity can be regarded as flood flow. This is far from being a general fact. As the height of the ground-water table increases the stream discharge also increases, and it is possible to have high and low waters dependent entirely on the fluctuation of the ground-water discharge. In streams which cut the ground-water table and are clearly ground-water-fed streams, such as those on Long Island, a rise in the ground-water table changes the position of the head of the stream, and by thus increasing both the head and the area of discharge greatly increases the stream flow. The total range of the ground-water table near the coast is much less than near the ground-water divide, and the discharge during periods of high ground-water level may therefore be disproportionate to the changes in level recorded by the wells near the coast. Because of these great changes in the area of the discharge and the relatively free flow of the surface water, it often happens that the fluctuations of the stream height in the lower part of the stream are greater than the changes in the level in wells in the same region.

Heavy rains, with no surface run-off, may likewise produce sudden and considerable rises by increasing the spring flow by transmitted pressure in the manner described above (p. 42). In the 14-foot well at Lynbrook (p. 23), besides the sudden rises recorded for every rain, the water four times during the period of observation rose above the surface. In the first instance the water, much to the amazement of the observer, gushed over the top of the pipe a few minutes after the shower began, and, while after the pipe was raised this did not occur again, the records show that on several occasions the water rose higher than the ground surface. There appear, then, to be great and almost insurmountable difficulties in the way of the satisfactory separation of the stream discharge into spring or ground-water flow and flood flow.

[a] Min. Proc. Inst. Civil Eng., vol. 9, pp. 153, 156.
[b] Ann. Repts. Wisconsin Agric. Expt. Station, 1892, pp. 94-100; 1893, pp. 152-159; 1894, pp. 240-280; 1897, pp. 228-231.

It is the belief of the writer that in the eastern United States the portion of the total stream flow attributed to ground-water contributions is commonly greatly underestimated.

On Long Island Spear, from a comparison of the hydrographs of several of the streams near the south shore with the fluctuation in neighboring wells, has concluded that of the total stream discharge but 57 per cent is spring or ground-water flow.[a] This is an extremely low value, and from a consideration of the various factors involved it is believed that 90 per cent is much nearer the true value. On this basis the flood flow is but 3 or 4 per cent of the yearly rainfall.

In the simple equation, Rainfall − Stream flow = Evaporation, no account is taken of the underflow, it being assumed that all the ground water is returned to the stream above the point at which the measurement is made, an assumption which is far from correct. The result of this is to give to the evaporation a value just as much in excess of its true value as there is loss by underflow. Thus on Long Island, where the percolation is perhaps 60 per cent of the rainfall, the estimate of Spear[b] gives the total normal stream discharge as 33 per cent of the rainfall, and the estimates of the Brooklyn water department are still lower. This, according to the above formula, would give a loss by evaporation of 67 per cent, when it is actually about 40 per cent. It may be assumed, however, except in regions deeply covered with loose superficial material, such as Long Island, that the loss by underflow is less than the excess by flood flow, and that the total stream flow represents a quantity slightly larger than the percolation. With this in mind, some idea of the amount of percolation can be obtained from the following values:

Rainfall and run-off of drainage basins in the United States.

Drainage basin.	Years of record.	Average yearly rainfall.	Average yearly stream flow.	Percentage: Stream flow of rainfall.	Authority.
		Inches of depth.	*Inches of depth.*		
Watershed of southern Long Island		42.56	14.0	33.0	Spear.
Muskingum River, Ohio	1888–1895	39.7	13.1	33.0	Rafter.
Genesee River, N. Y.	1890–1898	40.3	14.2	35.0	Do.
Lake Cochituate, Mass	1863–1900	47.1	20.3	43.0	Do.
Mystic Lake, Mass	1878–1895	44.1	20.0	45.3	Do.
Croton River, N. Y	1868–1899	48.07	22.33	46.5	Freeman.
Neshaminy Creek, Pa	1884–1899	47.6	23.1	48.5	Rafter.
Sudbury River, Mass	1875–1900	46.1	22.6	49.0	Do.
Sudbury River, Mass	1875–1902	46.38	22.75	49.0	Metropolitan waterworks.
Perkiomen Creek, Pa	1884–1899	48.0	23.6	49.0	Rafter.
Connecticut River, Conn	1872–1885	43.0	22.0	51.0	Do.
Hudson River, N. Y.	1888–1901	41.2	23.3	52.7	Do.
Nashua River, South Branch, Mass.	1897–1902	51.32	27.56	53.7	Metropolitan waterworks.
Pequannock River, Conn	1891–1899	44.2	26.8	60.6	Rafter.

In this table the large loss by underflow in the Muskingum and Genesee drainage basins is evident.

ESTIMATION OF PERCOLATION FROM CHANGES IN LEVEL OF THE GROUND-WATER TABLE.

The broader and more important fluctuations of the ground-water table are clearly due to the infiltration of water, and attempts have been made repeatedly to estimate

[a] Rept. New York City Commission on Additional Water Supply, 1904, p. 829.
[b] Ibid., p. 795.

the amount of infiltration by the rise in the ground water. After having determined the available pore space, which is by no means a simple matter, it appears very easy to calculate the amount of water which will cause the water level to rise a few inches or a few feet. The method is an attractive one, with an appearance of exactness and simplicity, and has often been tried. The results have very little meaning, however, for the very important reason that the same rainfall under the same climatic conditions will produce very different rises in material of the same porosity; for, as pointed out previously (p. 38), the amplitude of the fluctuation increases with the distance from the ground-water discharge. Thus, with material of the same porosity, an annual rainfall of 25 inches produces at Wiener Neustadt a fluctuation in one well of 1 foot, and in another a fluctuation of 25 feet (Pl. IX). It is evident that a calculation of infiltration based on the rise of water produced in well No. 1, will give very different values from that of No. 2, and yet it may be confidently asserted that the same amount of percolation is received in both. Similarly, in the chalk region of England, the fluctuation in the same region ranges from a few inches to 50 or 100 feet. The impossibility of accurately calculating the amount of percolation from the rise of the ground-water table is evident.

REFERENCES RELATING TO WELL FLUCTUATIONS DUE TO RAINFALL AND EVAPORATION.

The bibliography relating to fluctuations of water in wells due to rainfall is naturally very extensive, and an attempt has been made to collect a few only of these titles, important either for their general bearing or their special reference to the United States:

AUCHINCLOSS, W. S. Waters within the Earth and Laws of Rainflow, Philadelphia, 1897.

Gives record of fluctuations in well at Bryn Mawr, Pa., 1886–1895, showing annual and secular fluctuations.

BARBOUR, ERWIN HINCKLEY. Water-Sup. and Irr. Paper No. 29, U. S. Geol. Survey, 1899, p. 28; Nebraska Geol. Survey, Rept. of State Geologist, vol. 1, 1903, p. 106.

States that wells in Nebraska show an annual fluctuation independent of the rainfall, with the maximum occurring in February.

CLUTTERBUCK, JAMES. Observations on the periodic drainage and replenishment of the subterraneous reservoir in the chalk basin of London: Min. Proc. Inst. Civil Eng. [vol. 2], 1842, pp. 155–165; 1843, pp. 156–159.

——— On the periodic alternations and progressive permanent depression of the chalk-water level under London: Min. Proc. Inst. Civil Eng., vol. 9, 1850, pp. 151–180, Pl. VI.

EMERY, FRANK E. Notes on fluctuations in height of water in an unused well: Eighth Ann. Rept. New York Agric. Expt. Station for 1889, 1890, pp. 374–375, fig.

Records monthly observations from December, 1886, to December, 1889, on a 40-foot well at Geneva, N. Y., which shows a single yearly period independent of the rainfall.

FORTIER, SAMUEL. A preliminary report on seepage water and the underflow of rivers: Bull. Utah Expt. Station No 38, 1895.

On p. 30, under heading "Effect of subsurface temperature on rate of flow," are given discharge, temperature, and rainfall at Denver Water Company's plant at Cherry Creek, from 1888 to 1891. This is an infiltration gallery in fine sand 15 feet below the surface, and the discharge shows a rather regular yearly fluctuation with a minimum in February–March and a maximum, normally, in August–November. This fluctuation is ascribed by Fortier to changes in soil temperature. It should be pointed out, however, that, while the annual changes in soil temperature do affect the rate of flow (see p. 59), the yearly maximum is independent of this fluctuation and the agreement here is merely a coincidence.

FREUND, ADOLPH (secretary). Bericht des Ausschusses für die Wasserversorgung Wiens, Österreichischen Ingenieur- und Architekten-Verein, 1895.

Pl. V, Graphische Darstellung der Wasserstände im Steinfelde, 1883–1888.

GERHARDT, P. I. Handbuch der Ingenieurwissenschaften, vol. 3, Der Wasserbau, pt. 1, 1892, pp. 46–51.

Under heading "Schwankungen des Grundwassers," gives a summary based largely on the reports of Soyka.

HEADDEN, WILHELM P. A soil study, pt. 4, The ground water: Bull. Colorado Agric. Expt. Station No. 72, 1902.

Gives data regarding effect of single showers.

KING, FRANKLIN H. Fluctuations in level and rate of movement of ground water: Bull. U. S. Weather Bureau No. 5, 1892, pp. 72–74.

Discusses instantaneous percolation after rains.

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Discusses "Elevation of ground-water surface due to precipitation and percolation," largely from standpoint of porosity.

LIZNAR, JOSEF. Ueber die periodische Änderung des Grundwasserstandes, ein Beitrag zur Quellentheorie: Gæa, vol. 17, 1881, p. 330; Meteorol. Zeitschr., Wien, vol. 17, 1882, pp. 368-371.

LUEGER, OTTO. Die Schwankungen des Grundwassers: Gæa, vol. 24, 1888, p. 630.

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Contain monthly observations of water level at many points in Michigan.

SOYKA, ISIDOR. Experimentelles zur Theorie des Grundwasserschwankungen: Vierteljahrsschrift für öff. Gesundheitspflege, vol. 4, 1885, p. 592.

——— Der Boden (Handbuch des Hygiene und der Gewerbekrankheiten, vol. 2, pt. 3), Leipzig, 1887, pp. 251-351.

Contains much of the material incorporated in the following report.

——— Die Schwankungen des Grundwassers mit besonderer Berücksichtigung der mitteleuropäischen Verhältnisse: Penck's Geographische Abhandlungen, vol. 2, pt. 3, Wien, 1888.

SPEAR, WALTER E. Long Island sources: Rept. New York City Commission on Additional Water Supply, appendix 7, 1904, pp. 816-826.

Discusses fluctuation in elevation of ground-water surface.

TODD, JAMES E. Water-Sup. and Irr. Paper No. 34, U. S. Geol. Survey, 1900, p. 29.

The normal yearly maximum is here tentatively referred to the melting of snows or floods.

TRIBUS, L. L. Trans. Am. Soc. Civil Eng., vol. 31, 1894, pp. 170, 391-395.

Reports (p. 170) that in driven wells in New Jersey, 50 feet deep, the effect of rain was rarely felt in less than thirty hours; gives curve (pp. 391-395) showing fluctuation of water level in 50-foot well at Plainfield, N. J., waterworks, 1891-1894. This shows normal annual curves slightly affected by pumping.

WOLDŘICH, JOHANN NEPOMUK. Ueber den Einfluss der atmosphärischen Niederschläge auf das Grundwasser: Zeitschr. Meteorol., Wien, vol. 4, 1869, pp. 273-279.

——— Ueber die Beziehungen der atmosphärischen Niederschläge zum Fluss- und Grundwasserstand: Mitt. d. Techn. Klubs zu Salzburg, pt. 1, 1869.

FLUCTUATIONS DUE TO BAROMETRIC CHANGES.

CHARACTER AND CAUSE.

Changes in air pressure have been observed to affect wells in two ways; in some there is an inflow and outflow of air, and in others a rising and lowering of the water level.[a] The rise or outflow occurs with a falling barometer, and the depression or inflow with a rising barometer. In the case of flowing wells, when the external air pressure decreases, the air within the earth expands, and, as the escape through the soil is greatly retarded by friction and as the well offers a free escape, it finds relief through the well tubing. The power of this blast evidently depends on the area tributary to the well, the loss by friction, and the rate of lowering of the outside pressure. On the other hand, with a rising barometer the external air flows into the pipe to supply the volume lost by the compression of the soil air or earth air. [illegible] water is interposed between this included air and the well, the well becomes a rough differential-pressure gage in which the maximum change possible is about 12 inches of water for each mercurial inch of variation in the barometric pressure.

Where there is no soil air suitably confined to produce the result just described the air and other gases in the water so increase its compressibility that a small though measurable result may be produced by the direct compression and expansion of the water. In the latter case the depth of water involved is an important factor and it is probably for this reason that on Long Island, where the earth air occurs only in the porous surficial soil, from which it is relatively free to escape, in the wells at Lynbrook fluctuations due to barometric changes are clearly noticeable only in the 504-foot well, and these are relatively small. An examination of Pl. VI shows that there are no indications of barometric influence on the curves from the 72-foot well, but that in the 504-foot well there is a striking resemblance. The similarity is, however, in some places due in part to other causes. Thus the elevations of the water on July 18-19, August 5, and September 16, while closely following the barometric

[a] See in this connection Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, figs. 3, 4, 5; Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, fig. 39, p. 73.

curve, are partly due to rainfall. This is indicated by the fact that somewhat similar abrupt barometric depressions on July 26, August 20, and September 4–5, when there were no important rains, did not produce similar elevations of the water in the well. There is a further point of resemblance and dissimilarity between the curve for the 504-foot well and the barometric curve. The well curve shows a very marked semidiurnal fluctuation, the two parts of which are generally of about the same value, although they sometimes merge into a pronounced diurnal wave, as on August 1, 2, and 3. In the barometric curve, although there is a tendency toward a semidiurnal well wave, it is nowhere well marked. The semidiurnal well wave is clearly not tidal. Its resemblance to the barometer curve is, however, sufficiently close to lead to the belief that it is largely barometric, but modified by some other element, perhaps the diurnal temperature wave which shows in the 14- and 72-foot wells (pp. 24–25).

REFERENCES RELATING TO WELL FLUCTUATIONS DUE TO BAROMETRIC CHANGES.

BLOWING WELLS.

BARBOUR, ERWIN HINCKLEY. [Blowing wells in Nebraska]: Water-Sup. and Irr. Paper No. 29, U. S. Geol. Survey, 1889, pp. 78–82; Nebraska Geol. Survey, Rept. of State Geologist, vol. 1, 1903, pp. 93–97.

FARRLEY, T. On the blowing wells near North Allerton: Proc. Yorkshire Geol. and Polyt. Soc., n. s., vol. 7, pt. 3, 1880, pp. 409–421, Pl. VII.

HARRIS, GILBERT DENNISON. [Blowing wells in Rapides Parish, La.]: Water-Sup. and Irr. Paper No. 101, U. S. Geol. Survey, 1904, pp. 60–61; Louisiana Geol. Survey, Bull. No. 1, 1905, pp. 59–60.

LANE, ALFRED C. Water-Sup. and Irr. Paper No. 30, U. S. Geol. Survey, 1899, pp. 55–56.
Records shallow blowing well in Michigan.

VEATCH, A. C. Prof. Paper U. S. Geol. Survey No. 44, 1906, p. 74.
Records reported occurrence of blowing wells on Long Island, New York.

CHANGES IN WATER LEVEL.

ATWELL, JOSEPH. Conjectures on the nature of intermitting and reciprocating springs: Trans. Phil. Soc. London, No. 424, vol. 37, 1732, p. 301; Trans. Phil. Soc. London from 1665–1800 (abridged), vol. 7, 1809, pp. 544–550.
Describes irregular fluctuations of short interval in springs at Brixam, near Torbay, in Devonshire called "Lay well." These, he supposes, are produced by the action of natural siphons. Perhaps they are barometric fluctuations.

DENIZET. Sources sujettées à des variations qui paraissent liées à l'état du baromètre: Comptes rendus, vol. 7, 1839, p. 799.
Reports that springs at Voize are affected by changes in barometric pressure, and that the discharge is directly related to the pressure, instead of inversely, as has been proved by more recent work.

GOUGH, JOHN. Observations on the ebbing and flowing well at Giggleswick, in the West Riding of Yorkshire, with a theory of reciprocating fountains: Jour. Nat. Phil. Chem. Arts, ser. 2, vol. 35, 1813, pp. 178–193; Mem. Phil. Soc. Manchester, n. s., vol. 2, 1813, pp. 354–363.
The water level in this well fluctuates irregularly at short intervals, and Mr. Gough suggests that the fluctuations are produced by the obstruction resulting from the natural accumulation of air bubbles in the outlet and the relief resulting from their irregular escape. He cities the irregular fluctuations of the Weeding well in Derbyshire and the Lay well near Torbay, as proving that the prevailing idea of the production of these phenomena by natural siphons is erroneous. He concludes, very correctly, that too little is known of the fountain of Jupiter in Dodona and Pliny's well in Como to judge of the true cause of the fluctuations mentioned by Pliny.

KING, FRANKLIN H. [Influence of barometric changes on discharge and water level in wells and springs at Madison and Whitewater, Wis.]: Bull. U. S. Weather Bureau No. 5, 1892, pp. 44–53; Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, pp. 73–77.

LATHAM, BALDWIN. On the influence of barometric pressure on the discharge of water from springs: Brit. Assoc. Rept. for 1881, 1882, p. 614; Brit. Assoc. Rept. for 1883, 1884, pp. 495–496.
The fluctuation of the Croydon Bourne, due to barometric pressure, on one occasion exceeded half a million gallons per day. Observations in deep wells are also recorded, showing that fluctuations are inversely related to the pressure. The fluctuations are attributed to the expansion and contraction of the air and gases in the water.

KNIGHTLEY, T. E. Ebbing and flowing wells [in Derbyshire, England]: Geol. Mag., n. s., decade 4, vol. 5, 1898, pp. 333–334.
Suggests that irregularities in flow are due to cavernous limestone, which, by means of natural siphons, *gives rise to "intermittent* spring phenomena." The possibility of these fluctu*ations being due to barometric changes* is not considered.

LUEGER, OTTO. Einfluss der Atmosphärendruckes auf die Ergiebigkeit von Brunnen und Quellen: Centralblatt d. Bauverwaltung, 1882, p. 8.

MILNE, JOHN. Seismology. London, 1898, p. 243.

Reports two sinkings and two risings of about 5 millimeters in a shallow well near Tokio. The sinkings took place between 2 and 6 p. m. and 2 and 5 a. m. Note: These fluctuations suggest the diurnal barometric wave, but they can be referred to it only if the time given is taken to mean the time at which the water commenced to sink and not the time of the low-water stage.

OLIVER, Dr. WILLIAM. Of a well that ebbs and flows . . . : Trans. Phil. Soc. London, No. 204, vol. 17, 1693, p. 908; Trans. Phil. Soc. London from 1665–1800 (abridged), vol. 3, 1809, pp. 585–596.

Describes well near Torbay called "Lay well," that ebbs and flows from 16 to 20 times per hour. See Atwell, above, and discussion of minor periodic fluctuations on p. 75.

PLINY THE YOUNGER (Caius Plinius Cæcilius Secundus). Epistolæ, lib. 4, epist. ult.

In his letter to Licinius Pliny describes the fluctuations in the discharge of a spring near his villa in Como, Italy, which he states ebbs and flows thrice a day. He suggests that the fluctuations may be due to "the obstruction of air," tidal action, or some secret and unknown contrivance in the nature of a valve. Pliny the elder, in his Historia Naturalis, lib. 2, cap. 106, refers to the same spring, but states that it ebbs and flows every hour—a statement which is verified by Catanæus, the learned commentator on the Epistles. From the meager and contradictory data given it is unsafe to venture a decided opinion on the cause of these fluctuations, but they may be tentatively regarded as barometric.

ROBERTS, ISAAC. On . . . the variation in atmospheric pressure . . . causing oscillations in the underground water in porous strata: Rept. Brit. Assoc. for 1883, p. 405.

States that autographic records from a well at Maghill, near Liverpool, show such fluctuations.

SLICHTER, CHARLES S. Water-Sup. and Irr. Paper No. 67, U. S. Geol. Survey, 1902, pp. 71–72.

Refers to reports of Latham, King, and Lueger.

TODD, JAMES E. Bull. Geol. Survey, South Dakota, No. 2, 1898, p. 116; Water-Sup. and Irr. Paper No. 34, U. S. Geol. Survey, 1900, p. 29.

Reports that well discharge varies inversely with barometic pressure.

FLUCTUATIONS DUE TO TEMPERATURE CHANGES.

OBSERVATIONS AT MADISON, WIS.—FLUCTUATIONS VARYING DIRECTLY WITH THE TEMPERATURE.

In 1888 King observed in certain shallow wells at Madison, Wis., that the water regularly for a portion of the summer months stood higher in the morning than at night.[a] Further observations during the period 1888 to 1892 showed that there was in many wells a diurnal wave, distinctly marked during the summer and dying out in winter, which was clearly not barometric in character, and was not produced by the unequal plant transpiration during the day and night. Suspecting that these changes were intimately related to temperature, King tried the following experiment:

A galvanized-iron cylinder, 6 feet deep and 30 inches in diameter, provided with a bottom, and water-tight, was filled with soil, standing its full height above the ground in the open field. In the center of this cylinder and extending to the bottom a column of 5-inch drain tile was placed and the soil filled in about it and packed as thoroughly as practicable. Water was poured into the cavity formed by the tile until it was full, and allowed to percolate into the soil so as to saturate it and leave the water standing nearly a foot deep in the well. When the water in this artificial well had become nearly stationary one of the self-registering instruments was placed upon it.[b] In order to avoid any complications due to percolation, the apparatus was provided with a cover which could be put on in times of rain and removed again during fair weather. The first records showed a small diurnal oscillation, and as the season advanced these increased in amplitude until finally the water rose in the well during the day of July 8, 1.8 inches and fell during the following night 1.84 inches. After these diurnal oscillations had become so pronounced and so constant, a series of thermometers were introduced into the side of the cylinder, extending to different distances from the surface, and a record kept of the changes in the soil temperature; and the result of these observations was to show that the turning points in the water curve fell exactly upon the turning points of the temperature of the soil in the cylinder. When this fact was ascertained, to show whether the correspondence in the time of the two curves was due to a diurnal cause, other than temperature, which had its turning points so related to those of the temperature as to cause the two to accidentally fall together, cold water was

[a] King, Franklin H., Observations and experiments on the fluctuations in the level and rate of movement of ground water on the Wisconsin Agricultural Experiment Station Farm and at Whitewater, Wis.: Bull. U. S. Weather Bureau No. 5, 1892; also Ann. Repts. Wisconsin Agric. Expt. Station, 1889–1893.

[b] For a figure of this apparatus see Bull. U. S. Weather Bureau No. 5.

ought from the well and, with a spray pump, applied to the surface of the cylinder all around. ie water was applied on a hot sunny day, just after dinner, when the water was rising in the well, d the result was an immediate change in the curve, the water beginning to fall in the well. The ater was then turned off, and the result of this change was to stop the fall of the water in the well, shown by a change in the direction of the curve.

This led to the conclusion that there was a very positive connection between the anges in the soil temperature and changes in the level of the water in the wells, d that the fluctuation varied directly with the temperature; that is, the water in e wells rose with increasing temperature and fell when the temperature lowered. specially constructed self-recording soil thermometer showed that at a depth of inches the minimum temperature occurred at noon, and the the maximum a little ter midnight. It was therefore argued that at a depth of 3 feet, or the level at iich the wells were fluctuating, the maximum and minimum temperature would cur still later, and that the high water which occurred in the wells at 8 o'clock in e morning was due to the maximum temperature falling at that time at that depth. ie autographic records, moreover, show that the well curves have the same characristic as the temperature curve—there is in both a comparatively sudden rise and a ng fall. King at first believed that these fluctuations were produced by a variation the capillary action of the soil resulting from the change in temperature,[a] but terwards concluded that the fluctuations were due not so much to "a change in the scosity of the ground water as to variations in pressure due to the expansion and ntraction of the gas confined in the soil within and above the water."[b]

Changes in capillary attraction and surface tension, due to temperature changes, e quite competent to produce fluctuations which are related to the temperature in ie way observed. A rise in temperature, by decreasing the capillary attraction, iuses some of the capillary water above the water table to be added to the zone of mplete saturation, and so increases the level of the water in wells. Conversely, a ecrease of temperature, by increasing the surface tension and capillary attraction, iuses water to be transferred from the ground water to the partially saturated zone ove it, and so lowers the water in wells. There is, then, a continual interchange, flux and reflux, between the ground water and the water in the partially saturated ne above it. The amount of water involved in this change is probably small, but, ecause of the very small amount of unoccupied pore space existing immediately above e zone of saturation, a very slight shifting of water can produce a fluctuation of seval inches in the surface of the zone of saturation or the water level in a well. This fect is marked only when the bottom of the well (supposing the well tube to be ipervious) is very near the top of the ground-water table; it is not shown in deep ells because, while the position of the ground-water table is constantly changing in is way, there is, so far as deeper points are concerned, no important change in ressure. The total pressure at a given point below the ground-water table is essenally the same whether the water involved is in the saturated zone or 2 or 3 inches ove it in an almost saturated layer. To this, more than to the fact that the varitions in soil temperature at a given depth are less in winter than in summer, is due he fact that these fluctuations at Madison, Wis., were not shown by the twice-daily bservations, made morning and evening between 1888 and 1892, until past or near he middle of July (when the water was nearing its yearly minimum), and from that ime increased toward a maximum, occurring sometime in August (probably correponding with the ground-water minimum), and then died away until the middle of October, when they became inconspicuous. It likewise explains the fact that not ll the wells observed, though they were in a limited area, show these fluctuations, nd why they begin at different times in adjacent wells of different depths.

[a] Bull. U. S. Weather Bureau No. 5, 1892, pp. 63, 67.
[b] Bull. U. S. Weather Bureau No. 5, 1892, p. 72. Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 99, pp. 75, 77.

To this relation are due the apparently anomalous phenomena observed in "well No. 5," which King records as follows:

The ground-water level had fallen until well 5 was likely to become dry. In order not to lose the records it was deepened by boring a hole in the center and curbing it with sections of 5-inch drain tile in the manner represented in the figure,[a] which shows the two water surfaces whose fluctuations are recorded in fig. 16. The original well, having an inside diameter of 1 foot and a depth of 5.5 feet, was bricked up to within 2 feet of the surface and then finished with a section of sewer pipe, as shown in the cut,[a] where the character and arrangement of the soil through which the well penetrated may also be seen.[b]

The facts are, strange as it does appear, that under these conditons and in such close juxtaposition, oscillations so unlike in their character as the two under consideration were produced simultaneously. The level of the water in the outer well oscillated so as to stand in the morning from 0.1 to 0.3 inch above the level of the water in the inner one, and at night from 0.5 inch to 1.2 inches below that surface, and these differences were maintained with only the unglazed section of drain tile separating them. The large oscillations in this well became very pronounced and constant only a short time before it became dry, and the inner well did not take up the marked changes in level after the water fell below the bottom of the original well. No other well of this series, although constructed in the same manner, showed such marked oscillations.

The second suggestion, that the fluctuations are produced by the expansion and contraction of the air due to temperature changes, is not supported by the observed facts. The daily temperature fluctuation at the depths observed amounts to but a fraction of a degree, and the change in volume or vapor tension of the air resulting from this is quite incompetent to produce the fluctuations observed. Moreover, this involves an elevation in the well due to pressure of much the same character as that producing the fluctuations due to barometric changes. The effects of such pressure changes are felt not only at the surface of the zone of complete saturation, or the water table, but are transmitted for many feet below it, and in the case of well No. 5, described above, the fluctuations under such conditions would be shown in both wells, though in the deep one the amplitude would be slightly less.

On the whole there seems to be no other alternative than to regard these Madison fluctuations as the result of variations in the capillary attraction and surface tension, of the water above the zone of complete saturation, produced by variations in temperature.

In fluctuations of this character a limiting factor is clearly the range of temperature, which decreases very rapidly with depth, so that at a relatively shallow depth, much less than the limit of no annual change, the fluctuations become imperceptible. The amplitude will, moreover, be affected by the size of the pore spaces, being greater in fine than in coarse material.

OBSERVATIONS AT LYNBROOK, N. Y.—FLUCTUATIONS INVERSELY RELATED TO TEMPERATURE.

Two of the wells at Lynbrook show pronounced fluctuations which are clearly due to temperature changes. These fluctuations, while they resemble those observed at Madison in the fact that the water is higher in the morning than at night, differ from them in two important respects. There is no connection between their occurrence and the relation of the ground-water table to the bottom of the well; they are best developed in a 2-inch well, 14 feet deep, whose bottom is about 13.75 feet below the ground-water level; they are distinctly developed in a well 72 feet deep, and are believed to form one of the elements in a compound curve obtained from the 504-foot well (Pl. VI, p. 24). There is also the further difference that, while these are clearly temperature fluctuations, they are inversely related to the temperature—that is, the water is high when the temperature is low. Avoiding all discussion of the

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[a] Omitted in this report.

[b] The stratification, as shown in the original cut, is as follows:

Section of well at Madison, Wis., which furnished fluctuations shown in fig. 16.

	Feet.
1. Loam	0.6
2. Clay	3.0
3. Sand	.9
4. Clay	.3
5. Sand	2.0

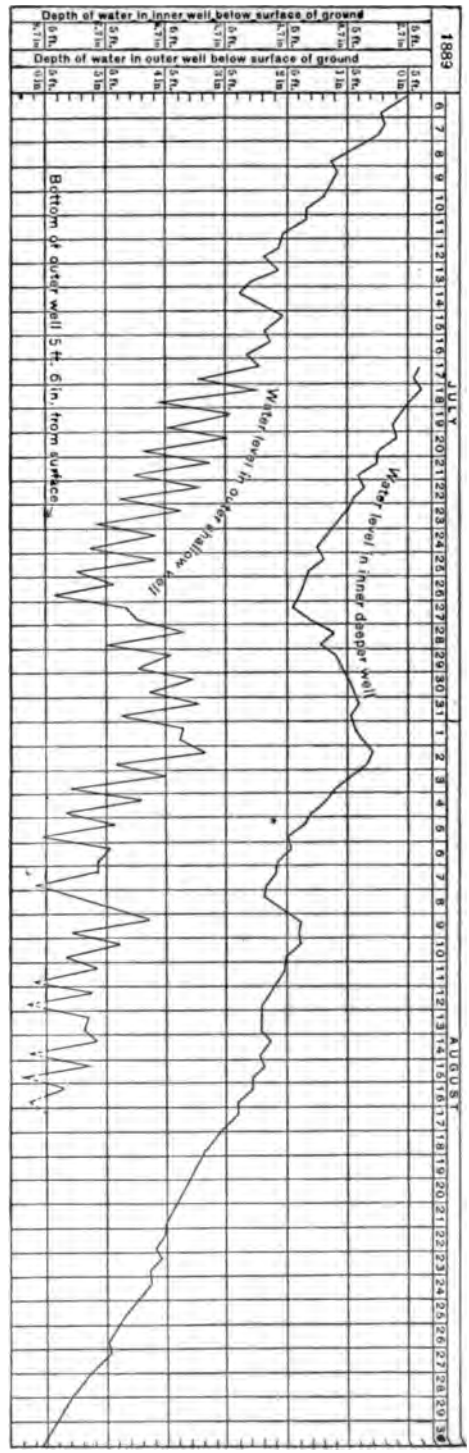

FIG. 16.—Record showing nontransmission of diurnal fluctuations produced by changes in capillary attraction due to temperature changes. Note sudden appearance of diurnal oscillations in large well a short time before it became dry and the absence of such fluctuations in a small well sunk inside of the large one. (Based on the twice-daily observations of King at Madison, Wis.)

question of lag, this relation is conclusively shown by the shape of the curves. The characteristic of the air temperature curve is a quick rise and slower fall; well fluctuations directly related to the temperature, as those at Madison, therefore must show a quick rise and a slower fall, but in the Lynbrook wells there is a quick fall and slower rise (see Pl. VI, Aug. 1–3). These evidently belong in quite a different class from the temperature fluctuations observed at Madison, and involve quite a different relation between the soil temperature and the ground water.

The soil is a very poor transmitter of heat, and there is not only a very rapid diminution of the temperature range with depth, but a very considerable time lag. Swezey' observations [a] at Lincoln, Nebr., for a period of fourteen years show that while in winter the maximum temperature occurs in the air at about the middle of the afternoon, at a depth of 3 to 6 inches it occurs in the evening, and at 1 foot it is delayed until the following morning; below 1 foot it is scarcely appreciable. In summer the daily range is considerably greater at all depths, the changes are appreciable to a depth of at least 2 feet, and are retarded to abou the same extent as in winter.

At Bronx Park, New York City, the record obtained by MacDougal [b] with a Hallock thermograph showed that at 1 foot below the surface the maximum daily temperature occurred between 8 and p. m., and the minimum between 8

[a] Swezey, G. D., Soil temperature at Lincoln, Nebr., 1888 to 1902. Sixteenth Ann. Rept. Nebraska Agric Expt. Station for 1902, 1903, pp. 95–129; Expt. Station Record, vol. 15, 1904, pp. 460–461.

[b] MacDougal, Daniel Trembly, Soil temperatures and vegetation. Monthly Weather Review, vol. 31, August, 1903, pp. 375–379.

and 10 a. m.; and the maximum daily range was but 2° C. (3.6° F.), which was reached on but two occasions. The total annual variation from June 9, 1902, to May 31, 1903, was 16.2° C. (29.4° F.). Similar results have been obtained by Callender at Montreal.[a]

As a result of this slow transmission of temperature, the temperature at the ground-water outlet may be at its maximum while a short distance away where the water table is but a foot or two from the surface, the ground temperature may be at its minimum. Now, the rate of flow of water is greatly affected by temperature. Poiseuille found that water at a temperature of 45° C. flowed 2.5 times as fast under otherwise like conditions as water at 5° C.[b] This gives rise to the phenomena shown in fig. 17.

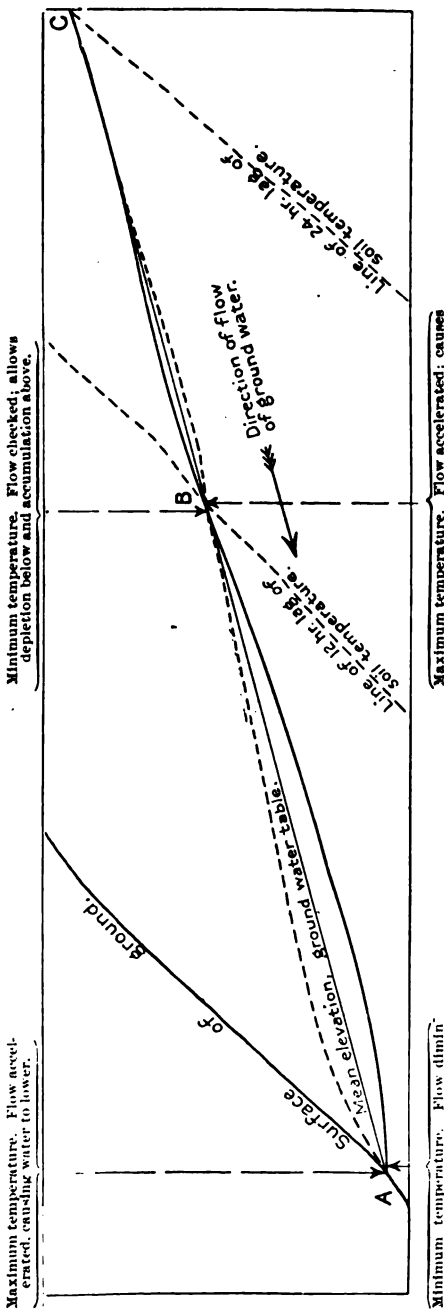

FIG. 17.—Diagram showing production of fluctuations of ground-water level by temperature changes affecting rate of flow. At the time of the maximum temperature at *A*, a minimum occurs at some point *B*, a distance of 1 or 2 feet from the surface. The effect of the increase in temperature is to increase the rate of flow, and of the lowering to decrease the flow. The flow is therefore checked at *B* and accelerated at *A*, and a partial depletion occurs between *A* and *B*, causing low water. When the minimum temperature occurs at *A* and the maximum at *B*, the reverse occurs, causing an elevation of the water. The maximum effect is much nearer *A* than *B*, because of the greater range in temperature, and the fluctuations, therefore, appear to be inversely related to the temperature.

There is thus produced a distinct and periodic fluctuation of the ground water, which is great near the ground-water outlet and decreases rapidly in amplitude as the distance from the outcrop increases. The fluctuation is produced by an actual shifting of the water whereby the pressure conditions are constantly changed, and in this respect it differs from the Madison fluctuations (p. 54). It is this change in pressure that causes these fluctuations to show in the other wells, even to a depth of 500 feet. The same phenomenon of response to loading and relief from load is exhibited in some of the rainfal fluctuations described above (p. 42) and in the sympathetic tidal fluctuations (p. 65).

[a] Callender, Hugh L., Proc. and Trans. Royal Soc. Canada for 1895, 2d ser., vol. 1, sec. 3, p. 79, fig. 4.
[b] Quoted by King, Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, p. 82; see also Carpenter, L. G., Seepage and return waters from irrigation: Bull. Colorado Agric. Expt. Station No. 33, 1896, pp. 42–44.

These data suggest that the annual changes of the soil temperature may produce a somewhat analogous effect, the warm summer temperature assisting in the depletion or lowering of the water near the ground-water outlets, and the cold winter temperature, by rendering the water more viscous, retarding the outflow. In one respect the result would be in the same direction as the annual ground-water fluctuations, and this is perhaps to be considered one of the minor factors. It would also tend to make the time of occurrence of the maximum and minimum of the yearly fluctuation earlier near the ground-water outlets than on the divides—or just the condition observed on Long Island (p. 35).

OBSERVATIONS AT SHERLOCK, KANS.

Diurnal fluctuations due to temperature changes were observed by Mr. Henry C. Wolff, at Sherlock, Kans., in 1904, while working under the direction of Prof. C. S. Slichter.[a] Mr. Wolff reports that the wells are low in the evening and high in the morning, and that there is no important time lag between wells where the water line is 6 inches below the surface and those where it is 3 feet below. In a few wells where the water level was about 3 feet from the surface, which were observed long enough to show the shape of the curve, the characteristics of the Madison curve are shown—that is, there is a long fall and sudden rise.

DIURNAL FLUCTUATIONS OF CACHE LA POUDRE RIVER, COLORADO.

Carpenter has observed very regular diurnal changes in the height of Cache la Poudre River near Fort Collins, Colo.[b] Here the high water occurs at from 4 to 6 a. m., the low water at 8 p. m., and the extreme range of the daily change in river level noted was about 1 foot. The curves show the same characteristics as those observed by Wolff at Sherlock, Kans.; there is a long fall and a sudden rise, and they are therefore directly related to the temperature. Carpenter concludes that these fluctuations are due to differences in daily melting in the snow fields, and that the occurrence of the high water in the morning is due to the distance from the snow fields. While this is a very possible explanation, and in the writer's opinion it is probably the correct one, it is desirable to have the matter checked by other observations. If the fluctuations are purely due to daily waves moving down the river, due to melting snow, gages at other points should show the maximum and minimum at different times; if the fluctuations are due to variation in rate of ground-water discharge and are analogous to those described above, the time will be the same at different points.

REFERENCES RELATING TO FLUCTUATIONS PRODUCED BY TEMPERATURE CHANGES.

Besides the references given above to the discussions of King, Slichter, and Wolff, it is desirable to add here the early reference of Pliny to fluctuating wells belonging to this class:

PLINY THE ELDER (Caius Plinius Secundus). Historia Naturalis, lib. 2, cap. 106 [Pliny's Natural History, Bostock and Riley's translation, Bohn's Libraries, vol. 1, 1887, pp. 133–134].

"In the island of Tenedos there is a spring which, after the summer solstice, is full of water from the third hour of the night to the sixth." "The fountain of Jupiter in Dodona . . . always becomes dry at noon, from which circumstance it is called 'The Loiterer.' It then increases and becomes full at midnight, after which it again visibly decreases." Hardouin notes that there is a similar kind of fountain in Provence called "Collis Martiensis." These fluctuations clearly belong to the class produced by temperature changes.

FLUCTUATIONS PRODUCED BY RIVERS.

Rivers may produce fluctuations of the water level in wells in three ways: (1) By changing the height of the ground-water discharge; (2) by seepage or actual contributions to the ground water, and (3) by transmitted pressure or plastic deformation.

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[a] The underflow of the Arkansas Valley in western Kansas: Water-Sup. and Irr. Paper No. 153, U. S. Geol. Survey.

[b] Carpenter, L. G., Bull. Colorado Agric. Expt. Station No. 55, 1901, figs. 2–6.

FLUCTUATIONS PRODUCED BY CHANGES IN RATE OF GROUND-WATER DISCHARGE.

In regions where the sides of the channels are pervious and the ground water contributes to the stream flow, the water table, after a period of long drought, slopes regularly down to the water surface. If the stream rises through causes not associated with local ground-water conditions, the ground-water table is found likewise to rise to a greater or less extent. This is accomplished in part by an outflow from the river and in part by the accumulation of the ground-water flow, which can not so readily escape under the new conditions as under the old. If this new level were permanently maintained a complete readjustment would take place, and a line roughly parallel to the initial position of the ground-water table would be developed; and if there were no new outlets developed by this elevation of the ground water, wells at all distances would be similarly affected. Actually, however, the river is constantly changing; a series of waves of unequal height and duration, representing the high and low waters, are constantly traveling down every stream, and no stage lasts long enough for the establishment of a perfectly graded ground-water table, even were there no other factors involved. The result of this unceasing change is that the fluctuations are greatest near the river and become imperceptible at very short distances. This is due not only to the rapidity of the fluctuations in the river, but to the slow rate of outflow and accumulation.

Observations made by Hess [a] along Aller River, near Celle, Germany, in 1866, give the values expressed in the table below:

Table showing lag of high- and low-water stages in wells along Aller River, behind high- and low-water stages in the river.

Test well No.—	Distance from river.	High water, Feb.-Mar., 1866.		Low water, Mar. 7, 1866.		High water, Apr. 1, 1866.	
		High water in well behind high water in river.	Rate per day.	Low water in well behind low water in river.	Rate per day.	High water in well behind high water in river.	Rate per day.
	Meters.	*Days.*	*Meters.*	*Days.*	*Meters.*	*Days.*	*Meters.*
1	47	5	10	2	23.5	4	12.5
2	140	5	28	3	47.0	5	28.0
3	351	17	21	4	88.0	10	35.0
4	468	19	24	7	67.0	.....	.....
5	584	21	28	.....	.....	.....	.....

Observations made by Slichter in very porous gravels in western Kansas, at Garden, Sherlock, and Deerfield, while showing a more rapid transmission than those just indicated, give very marked time lags. The conditions here are different in the respect that the ground water does not materially add to the stream flow, and the rise of the water in the wells is due wholly to seepage. The slope of the water plane is not toward the river, but downstream, at a rate very nearly the same as that of the stream. At Sherlock the water plane on July 27, 1904, sloped gently to the river from test well No. 5, but the water in test wells Nos. 2, 3, and 6 was lower than the river. Between 11 and 4 o'clock the river rose 1.6 feet, and then fell gradually. The beginning of the rise was felt in well No. 3, 400 feet north of the river, in less than two hours; in wells No. 2, 900 feet north of the river, and No. 5, 550 feet south of the river, in between three and four hours; in well No. 4, 1,000 feet south of the

[a] Hess, Beobachtungen über das Grundwassers der norddeutschen Ebene. Zeitschr. des Architekten und Ingenieurvereins in Hannover, vol. 16, 1870, quoted by Soyka, Der Boden, Leipzig, 1887, pp. 262-267, figs. 23-25; and Gerhardt, Der Wasserbau, Leipzig, 1892, pp. 49-50, Pl. I, figs. 7, 8. The diagrams given by Soyka and Gerhardt do not check with the values given in the text, and as the figures are clearly carelessly drawn the text values are reproduced here.

river, in four hours. Well No. 6, 2,500 feet from the river, fell during the whole period of observation. The difference in time in the occurrence of the maximum is expressed in the following table:

Difference in time between high water in Arkansas River and wells on its banks, near Sherlock, Kans., July, 1904.

No. of well.	Distance from river.	Lag.
	Feet.	*Hours.*
3	[a] 400	3-6
2	[a] 900	12
1	[a] 500	36
5	[b] 550	108+(?)
4	[b] 1,000	108+
6	[b] 2,500	(c)

[a] North.
[b] South.
[c] No rise in five days.

It will be noted that the most rapid transmission was toward the north, where the water plane sloped away from the river, while the slight rise of the water plane toward wells Nos. 4 and 5 produced a very marked retardation.

These observations seem to indicate that the rate of transmission is greater when the water plane slopes from the river than when it slopes toward it and help to explain the great retardation observed at Celle. In no instance in this Kansas work were the effects of floods observed in wells at distances of more than one-fourth of a mile from the river.

In case there is open connection between the river and the well, such as might be afforded by limestone caves, changes in level may be felt at considerable distances with but very little time lag. Very rapid fluctuations would, however, be obliterated here, for the well would act very much as the still box used in tidal work, which consists of a large well connected with the ocean by means of a relatively small passage opening at some distance below the water surface. The wave action is entirely obliterated, because the water does not have time to flow in and out of the well in the period between fluctuations. The gradual changes of the tide are, however, exactly recorded. But direct cavernous connections between wells and waterways are rare, and generally river changes act through the interstices of the soil in the way observed at Celle and Sherlock or by transmitted pressure as described below.

FLUCTUATIONS PRODUCED BY IRREGULAR INFILTRATION FROM RIVERS WITH NORMALLY IMPERVIOUS BEDS.

Besides rivers which have pervious sides and into which the ground water is always free to flow or out of which the water flows whenever the river level exceeds that of the ground water, there are many rivers which, under normal conditions, so plaster their beds with fine silt that water is unable to flow either in or out. Nearly all rivers carrying large amounts of fine silt[a] are normally in this condition, and it is thus that the water in many delta regions is able to flow at heights above the surrounding land, and rivers in other regions flow at heights much above the normal ground-water level.

Thus the Leitha at Katzelsdorf, near Wiener Neustadt, flows at a height of 10 to 70 feet above the level of the ground water at that place, the height depending on

[a] For an example of the silting power of a clear stream see Freeman, John R., Percolation through Embankments and the Natural Closing of Leaks, Boston Soc. Civil Eng., June 20, 1888.

the stage of the ground water, although there is at all times considerable seepage. (Pl. IX.)

The Rio Grande in a similar way flows from central New Mexico to the sea, always above the ground-water level.

When the rivers silt up their beds, where the water plane slopes down to the river and there is a tendency to discharge into the river, the silting develops an artesian head which causes the water to rise above the level of the river in wells sunk within the channel. Such occurrences have been reported by Salbach in the Elbe.[a] This Elbe occurrence may, however, be due to a sheet of clay not connected with the river-silt deposits of the present régime. During floods such rivers frequently scour out their beds and establish a connection between the surface and the underground waters. When the river is above the ground-water table, this leakage will raise the water level; when the reverse is the case, it may, by permitting a discharge of the artesian water, cause the water level in a near-by well to lower.

Slichter has found at Mesilla Park, N. Mex., that the greater part of the underflow in the valley is derived in this way from the flood waters of the Rio Grande.[b] Preceding the flood of October 5, 1904, the ground-water level was several feet below the river channel, although the river contained considerable water. The effect of the flood was well marked at well No. 7, three-fourths of a mile from the river, but did not affect well No. 6, 1.3 miles from the river, in seventeen days. The rate of transmission is evidently quite similar in this case to those given above.

Quite different from these slow rates of change in the ground-water level due to river changes are the changes in the London wells ascribed by Clutterbuck and Buckland[c] to floods in Colne River at Watford, Hertfordshire. According to these observers a rise in the Colne produces a rise in the London wells, 15 miles distant, in a few hours. These floods are due to heavy rains and it seems much more probable that the observed rise is due to the weight of the rain on the local London area than to the transmitted pressure from a flood 15 miles distant. Fluctuations of this character due to rainfall have been observed at Lynbrook, N. Y. (p. 42), and no such rates of lateral transmission have been observed either from the river flood or tides, with the possible exception of the tidal wells at Lille, France (p. 64.) Certainly there is no evidence of such great underground caverns between Lille and the sea as this rate of transmission would require, though its very occurrence, if conclusively proven, would indicate some such connection.

FLUCTUATIONS DUE TO A PLASTIC DEFORMATION PRODUCED BY VARYING VOLUMES OF WATER CARRIED BY RIVERS.

The alternations of load due to the irregular waves, whose crests are the high- and low-water stages, which are constantly passing down every river, produce fluctuations anagalous to those produced by tides, though lacking their periodic character. They resemble also the sympathetic fluctuations produced in the 72- and 504-foot wells at Lynbrook due to variations in load produced by rainfall and thermometric changes (pp. 43, 58). The zone in which these fluctuations will be distinctly recognizable will be limited to a mile or two in the immediate vicinity of the river.

REFERENCES RELATING TO FLUCTUATIONS OF THE WATER IN WELLS PRODUCED BY RIVERS.

BUCKLAND, DR. Min. Proc. Inst. Civil Eng. [vol. 2], 1842, p. 159.

Reports that wells in London rise in a few hours after floods at Watford, 15 miles distant.

CLUTTERBUCK, JAMES. Observations on the periodical drainage and replenishment of the subterraneous reservoir in the chalk basin of London: Min. Proc. Inst. Civil Eng. [vol. 2], 1842, pp. 156, 158; 1843, p. 162.

Same as under Buckland.

[a] Salbach (Baurath at Dresden, Saxony), Experiences had during the last twenty-five years with waterworks having an underground source of supply. Trans. Am. Soc. Civil Eng., vol. 30, 1893, p 314.

[b] Slichter, Charles S., Observations on the ground waters of Rio Grande Valley. Water-Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905, p 27.

[c] Min. Proc. Inst. Civil Eng., 1842, pp. 158, 159, 1843, p. 162.

FULLER, MYRON L. Notes on the hydrology of Cuba: Water-Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905.

Records, on p. 189, fluctuations of spring level at Vento, Cuba, due to changes in level of Almendares River, evidently acting through a free connection of large size in the limestone.

HARRIS, GILBERT D. Underground waters of south Louisiana: Water-Sup. and Irr. Paper No. 101, U. S. Geol. Survey, 1904, p. 14; Bull. Louisiana Geol. Survey No. 1, 1905, p. 4.

Discusses effect of Mississippi River on level of wells along its banks.

GERHARDT, P. Der Wasserbau, vol. 1, pt. 1, 3d ed., 1892, pp. 48–49.

Gives Hess's observations on Aller River.

SLICHTER, CHARLES S. Observations on the ground waters of Rio Grand Valley: Water-Sup. and Irr. Paper No. 141, U. S. Geol. Survey, 1905, pp. 18, 25–28, 30.

Gives observations on effect of outflow from river on ground-water level at El Paso, Mesilla Park, and Berino.

——— The underflow of the Arkansas Valley in western Kansas: Water-Sup. and Irr. Paper No. 153, U. S. Geol. Survey.

Gives results of observations on the influence of floods in Arkansas River on the water level in wells at Garden, Sherlock, and Deerfield, Kans., in the summer of 1904.

SOYKA, ISIDOR. Die Schwankungen des Grundwassers: Penck's Geographische Abhandlungen, vol. 2, pt. 3, 1888.

Chapter 3, "Die Beziehungen des Grundwassers zu den oberirdischen Wasserläufen," contains an excellent discussion of middle European conditions.

THOMASSAY, RAYMOND. Géologie pratique de la Louisiane, 1860.

Contains an entirely fanciful discussion of the seepage of the water from Mississippi River.

TODD, JAMES E. Geology and water resources of a portion of southeastern South Dakota: Water-Sup. and Irr. Paper No. 34, U. S. Geol. Survey, 1900, p. 29; Bull. South Dakota Geol. Survey No. 2, 1898, p. 116.

Records that many deep wells have a greater discharge when Missouri River is high, and suggests that the increased hydrostatic pressure checks the leakage.

VEATCH, A. C. Geology and underground water resources of northern Louisiana and southern Arkansas: Prof. Paper U. S. Geol. Survey No. 46.

Records fluctuations of water level in artesian wells at Fulton, Ark., agreeing with stages of Red River. These are ascribed to pressure of river water acting at the outcrop of the water-bearing sands in river bed several miles from the town. This probably is a case of transmitted pressure, the blue clay over the water-bearing layer acting as a diaphragm and producing fluctuations in wells near the river.

FLUCTUATIONS PRODUCED BY CHANGES IN LAKE LEVEL.

Variations in lake levels of whatever cause produce fluctuations of the level in wells along their shores (1) by checking the rate of outflow when the ground water is draining freely into the lake and (2) by transmitted pressure and deformation as in ocean tides described below. The pressure of deep-seated waters might also be slowly affected by the weight of the sediment deposited in the lake beds. This would tend to equalize itself by back flow, and is perhaps a factor of no great importance, except when considered for very long periods. King has, however, obtained a flow artificially by ordinary sedimentation in a tank.[a]

FLUCTUATIONS PRODUCED BY VARIATIONS IN THE OCEAN LEVEL—TIDAL WELLS.

As partially indicated in the references on page 67, wells and springs which fluctuate with the tide have been observed on nearly all coasts and under many different geologic conditions. These fluctuations are produced in three ways: (1) By transmission of pressure through open cavities or passageways affording a free communication between the wells and the ocean; (2) by a checking of the rate of discharge of the normal ground-water flow through porous beds freely connecting with the ocean; and (3) by a deformation of the strata due to the alternate loading and unloading of the tides. In this last case, instead of leakage being an important factor, as it is in the first two, the fluctuations are greater the more nearly complete the separation of the oceanic and ground waters.

[a] Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, pp. 79–80.

FLUCTUATIONS PRODUCED BY CHANGES IN RATE OF OUTFLOW.

The first two classes differ more in the rate at which the change takes place and the character of the zone of influence than in the manner in which it is produced. If the ocean level is raised the first effect is to check the velocity of outflow; but before any change occurs in the level of near-by wells it is necessary that water accumulate at the point of observation by actually flowing in. This change, then, is clearly dependent on the same factors which influence the rate of flow, and in underground caverns where the velocity is a question of miles per day this accumulation will be rapid, there will be a relatively short lag, and the distance from the shore to which the rise can be propagated before the water begins to fall will be comparatively great. Its influence will, however, be restricted to wells along limited lines, following the course of the underground passageway. On the other hand, when the water is flowing through the interstices of porous strata, where the motion is one of feet per day instead of miles, the accumulation will be slow, the lag proportionately greater, and the zone of influence, while not extending so far from the ocean, will perhaps occupy a larger area, because of its uniform distribution along the coast. When the ocean level falls the reverse will occur.

Where there is considerable velocity, as in a cavernous opening, the velocity of outflow retards the effect of the rising tide and hastens that of the falling tide and there is then, as in tidal rivers, a greater lag at low than at high water. When the outflow is slow, as from porous beds, the velocity is not sufficient to exert a very great retarding influence.

The fluctuations in porous materials along the seashore are clearly the same in character and cause as those occurring under similar conditions along river courses (see p. 60), and the same great time lag is to be expected. The difference is only in the very regular periodic nature of the oceanic fluctuations. Nearly all the shallow tidal wells noticed along the seacoasts belong to this class. Such are clearly the tidal wells[a] reported near Bombay and along the Malabar coast; at Barren Island, in the Andaman Sea; at Perim Island, in the Red Sea; at South Foreland light-house, Kent; the shallow wells at Seagirt, N. J.; and perhaps the wells at Newton Nottage, Glamorganshire, Wales, and Chepstow, Monmouth, England. At Perim Island, in shallow pits at a distance of 60 to 300 feet from the shore, the lag is such that the high water in the wells appears to agree with the low water in the ocean. A similar lag is reported in a well 14 feet deep and 400 feet from the river at Chepstow. At Newton Nottage, where a shallow well 500 feet from the ocean was observed by Mandan, the lag is but three hours.

Experience has shown that wells which are sunk entirely in porous beds near the seacoast should have their bottoms about midway between high and low tide; if they are deeper there is generally an infiltration of salt water. Such wells are commonly dry at low tide, but frequently furnish good supplies of fresh water at high tide, at which time it is necessary to obtain all the water used for domestic and other purposes.

Wells dependent on underground cavernous openings, such as required by the first case, are quite rare. The fluctuations of the Iceland springs, reported by Hallan de Roucroy, are perhaps connected with such open fissures, though any opinion from the data presented is but a hazard. Perhaps the most remarkable occurrence of tidal fluctuation is that reported at Lille in an artesian well at the citadel. These fluctuations, which amount to 0.415 meter, are referred by Bailly[b] to the tides of the English Channel, 30 miles away, with a time lag of but eight hours. The only basis on which these fluctuations can now be explained is a supposition of a relatively open connection between the well and the ocean, which, it must be admitted, is a very unsatisfactory hypothesis.

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[a] See references, pp. 67–69.

[b] Comptes rendus, vol. 14, 1842, pp. 310–314.

TIDAL FLUCTUATIONS IN WELLS PRODUCED BY PLASTIC DEFORMATION.

sides the shallow wells, depending on ordinary porous surficial beds, there are, g and near the seacoast, many deep artesian wells which show tidal fluctuations. nany of these wells there are clearly no underground caverns involved, the r-bearing beds being ordinary porous strata in which the water flows through mall interstices at a rate to be expressed in feet rather than miles per day, and hich accumulation or depletion by simple flowage will be correspondingly slow. e is, moreover, every reason to believe, in some cases where there are thick clay above the water-bearing strata, which are known to be continuous for many s, that there are no near suboceanic outlets of importance. In case there is distant outlet it is evident from the slow rate of change shown in the examples 1 above, where there was a sudden increase or decrease in the volume of river r (pp. 60, 61), that the fluctuation produced by a simple checking or hastening of ate of outflow could be propagated but a short distance, and that a long period ne would be necessary for even that.

ere is, however, in the case of waters under artesian head a new factor intro- d which is of very great importance. The pressure of the artesian water exerted nst the retaining cover, which may be assumed at present to be clay, tends evate it, thus placing the clay under an upward stress. The addition of any ht on the surface tends to disturb the equilibrium. If there is no outlet and the ht is applied uniformly, the additional weight can not change the position of portion of the mass, except to the very slight degree of the elastic compressibility e water and the soil. If, however, there is any escape for the confined water, as would be afforded by a well tube, the mass will yield and the water be forced 1 the tube. Were the clay layer perfectly elastic, or in the condition of a ched elastic membrane above a perfectly mobile body, there would be no time lag, the water in the well would exactly follow the fluctuations of the ocean waters; the clay is not to be regarded as an elastic diaphragm, and the water-bearing is not a perfectly mobile body; moreover, for such a deformation to be felt in ll water must be transferred from one point to another, and this involves a time ent. The deformation is essentially a plastic one; the clay yields to the super- d weight and the water is lifted in the well, but if there were no pressure from w the clay could not return to its original position. In the case of tides along coast only the portion of the clay layer under the ocean is loaded, and that load- s a progressive one from a distant point toward the shore. The effect is a defor- on in which the clay layer is depressed under the ocean and elevated under the . When the weight is removed the artesian pressure tends to reestablish the conditions of equilibrum, and the clay layer is lifted under the ocean and sinks er the land.

the artesian pressure is high, compared with the tide when the ocean water com- ces to fall after high tide, this pressure lifts the clay quickly and thus tends to ten the high-tide lag in a near-by well; as the tide falls the high pressure enables clay to follow the tide closely; at low tide the artesian pressure is clearly in the ndancy and the clay still rising in the ocean area. As the tide begins to rise it t overcome this artesian pressure before any deformation occurs, and the rising e in the well therefore lags more behind the tide than the falling curve. Under conditions the high-tide lag is less than the low-tide lag. Conversely, when the ian pressure is low compared with the tide, at high tide the feeble artesian pres- but slowly lifts the clay weight and the lag is long; at low tide, when the clay hragm is high, the greater tidal weight quickly overcomes the feeble resistance of rtesian water and the lag is short; it may then happen that the low-tide lag will ss than the high-tide lag.[a] It is evident that between the two extremes thus

[a] This plastic deformation should not be confused with the elastic deformation of the earth which Ihn has considered in his calculations of the effect of tides on seacoasts. He assumes that the

indicated there are all possible variations, and that the thickness and plasticity of the beds above the water-bearing layers are important modifying factors. The fluctuation in a well in such cases does not furnish an exact measure of the amount of deformation; it furnishes only a fair indication of the variation in pressure at the particular point at which the well is sunk.

The maximum effect is felt at the seacoast near low-tide mark and gradually decreases inward, disappearing in a few miles. It is less if there is leakage from sub-ocean springs, for in such cases the escape of the water decreases that available for the elevation of the water in the tube.

On Long Island the tidal fluctuations observed in the wells at Huntington, Oyster Bay, Long Beach, and Douglaston are clearly of this character, all depending more on the deformation of the overlying layer through tidal load than on changes of discharge in leakage. At Huntington (p. 10), Oyster Bay (p. 13), and Douglaston (p. 25) the lag is greater at low than at high tide, as would be expected from the great head and shallow depths, while at Long Beach, where the head is low, the water-bearing sand fine, and the thickness of overlying strata great, the reverse is true (p. 19). The Oyster Bay observations give the following values:

Summary of observations on tidal wells at Oyster Bay, N. Y.

Well.	Depth.	Distance from ordinary high tide.	Low-water lag.	High-water lag.
	Feet.	*Feet.*	*Minutes.*	*Minutes.*
Casino	93	In water.	12.6	8.0
Burgess	155	50	33.4	24.7
Lee	188	100	58.0	42.0
Underhill	114	500	75.6	71.8

It will be noticed that the lag here increased with the distance from the shore, and that the low-water lag increased more rapidly with depth than the high-water lag. The cause of the very small difference between the high- and low-water lags in the Underhill well, the one farthest from the shore, is not clear, but it is apparently related to the lessening of the tidal influence with the increasing distance.

The Long Beach well is affected both by the tide in the ocean and in the channels behind it, the curve being, as would be expected, a simple resultant of the two stresses. Because of the shallow bars at the openings the irregularity in the height of the inner low tide is less than in the ocean, and the effect of this difference is shown in the greater regularity of the low-tide heights in the well than in the ocean (Pl. IV, p. 20). Here the high-tide lag is one hour and nineteen minutes and the low-tide lag forty minutes, when compared with the ocean, while compared with the tide behind the bar the high-tide lag is practically nothing and the low-tide lag is nearly two hours.

To this same class belong nearly all the deep artesian wells along the seacoast which fluctuate with the tide. The phenomenon observed is the result of actual deformation, and the occurrence of tidal fluctuations in deep wells does not, as has been commonly supposed, prove a connection between the water-bearing strata and the ocean. Examples of this type are afforded by the deep wells along the New Jer-

earth has an elasticity equal to twice that of the stiffest glass, and the elastic compression produced by loading a sphere of such material of the same size as the earth with a tide of 5 feet is calculated on the supposition that the ocean is in the shape of a narrow canal. According to this the tides on the Atlantic coast may cause the land to rise and fall as much as 5 inches. See Darwin, G. H., On variations in the vertical due to elasticity of the earth's surface: Brit. Assoc. Rept., 1882, p. 388; Phil. Mag., 5th ser., vol. 14, 1882, pp. 409–427. The Tides, Boston and New York, 1898, pp. 139–143, quoted by Milne, J., Nature, vol. 38, 1883, p. 367, Seismology, London, 1898, pp. 236–237.

sey coast, the wells at Pensacola, Fla., the deep wells at Greenwich Hospital, London, and the wells along the Lincolnshire and Yorkshire coasts.

Shelford[a] has presented a very clear diagram of the conditions on the Lincolnshire coast. This shows overflow springs occurring at the top of a porous layer and the base of an impervious one, and the relation between ordinary overflowing and tidal wells, all depending on the same strata. Here, as is almost universally the case, the tidal wells occur only on the shore, and the wells 2 and 3 miles inland are not affected. In explaining the phenomenon Shelford supposed that the water found an outlet in Silver Pit, a deep hole in the ocean bed about 18 miles from the coast, which he has represented in his drawing as the ground-water outlet, and that changes in level in the discharge produced the tidal fluctuations. Such a simple change in the rate of discharge could affect the wells 18 miles distant only if there were a large open cavernous connection. That there is no such cavern is shown by the fact that the effect diminishes very rapidly in passing inland, entirely dying out in 2 miles. There is no reason why the effect should be propagated 18 miles to the coast and then suddenly cease, when tidal wells of the same character penetrating a thick clay bed and obtaining water in the upper porous layer of the chalk occur along the whole Lincolnshire and Yorkshire coast. In many cases springs near the coast, deriving their supply from the water beneath the clay, are likewise tidal. The cause of this phenomenon in the Bridlington Quay wells, Yorkshire, was correctly given by Inglis in 1817. He recognized in the clay layer a moving diaphragm affected by the tidal pressure from above and the artesian pressure from below.

REFERENCES RELATING TO TIDAL FLUCTUATIONS IN WELLS AND SPRINGS.

ANONYMOUS. London Athenæum, August, 1860; Jour. Franklin Inst., vol. 72, 1861, pp. 309–310.

States that tides in wells near the sea are universal, and records their occurrence about Bombay and along the Malabar coast wherever the material dug through is porous. Wells dug in trap rock are not tidal.

BAILLY. Rapport sur les variations observées dans la dépense du puits artésien de l'hôpital militaire de Lille et dans les hauteurs de la colonne d'eau quand on a interrompu l'écoulement: Comptes rendus, vol. 14, 1842, pp. 310–314.

Gives observations showing that fluctuations, having a range of 0.415 meter, are clearly tidal and occur eight hours behind the tide on the adjacent coast between Dunkerque and Calais. Reports that tidal wells also occur at Noyelle-sur-Mer, Département de la Somme, and at Fulham, London, England.

BRAITHWAITE, FREDRICK. Min. Proc. Inst. Civil Eng., vol. 9, 1850, p. 168; vol. 14, 1855, pp. 507–522.

"At Greenwich Hospital, London, the land springs ebb and flow 2 feet 6 inches, the sand springs, 3 feet, and the chalk springs, 4 feet 6 inches every tide." The total depth of the chalk well referred to is 149 feet.

CHRISTIE, JAMES. Jour. Franklin Institute, vol. 101, 1901, p. 193.

Reports fresh-water well near shore which fluctuates with the tide.

CLUTTERBUCK, JAMES. Min. Proc. Inst. Civil Eng., vol. 9, 1850, p. 170.

Explains tidal fluctuation in wells on basis of leakage between high- and low-tide marks.

——— Min. Proc. Inst. Civil Eng., vol. 14, 1855, pp. 510–511.

Wells at Ramsgate, England, are sunk to half-tide level. These begin to fall at half tide, are dry at low tide, and begin to rise at half tide on the flood.

——— Min. Proc. Inst. Civil Eng., vol. 19, 1860, p. 33.

Reports that wells at Portsmouth, England, are tidal, and concludes that this proves a free connection with the sea.

DESAGULIERS, Rev. J. T. An attempt to account for the rising and falling of the water of some ponds near the sea, etc. Trans. Phil. Soc. London, No. 384, vol. 33, 1724, p. 132; Trans. Phil. Soc. London from 1665–1800 (abridged), vol. 7, 1809, pp. 39–41.

Reports well at Greenhithe in Kent, between London and Gravesend, which appears to fluctuate inversely with the tide. This he explains by imagining a natural siphon.

DOUGLAS, JAMES NICHOLS. Min. Proc. Inst. Civil Eng., vol. 47, 1879, p. 88.

Chalk well at South Foreland light-house, Kent, England, 283 feet from face of cliff, 280 feet deep, with bottom level with half tide, has a peculiarity common to many wells of this region in that it is dry at low tide and filled with pure spring water at high tide.

[a] Shelford, W., Min. Proc. Inst. Civil Eng., vol. 90, 1887, p. 69.

FRAZER, PERSIFOR. Notes on fresh-water wells of the Atlantic beach: Jour. Franklin Inst., 1890, vol. 130, p. 231.

Reports well at Sea Girt, N. J., 29 feet deep, which rises and falls with tide in ocean 150 feet distant.

HALLAN DE ROUCROY. Comptes rendus, vol. 12, 1841, pp. 1000–1001.

States that well at Lille, France, shows tidal fluctuations.

HUTTON, Capt. F. W. Trans. and Proc. New Zealand Inst., 1895, vol. 28, 1896, p. 655.

States that artesian wells at New Brighton are affected by the tide.

INGLIS, GAVIN. On the cause of ebbing and flowing springs [at Bridlington, Yorkshire]: Phil. Mag., vol. 50, 1817, pp. 81–83.

"When the recess of the ocean lessens the pressure upon the upper surface, the hydraulic pressure on the under stratum must raise the whole mass in proportion as the force is superior to the resistance. The return of the tide brings with it the weight and altitude of its mass of water and acts on the flexibility of the clay as a pressure would on a hydraulic blowpipe."

KING, FRANKLIN H. Fluctuations in the level and rate of movement of ground water: Bull. U. S. Weather Bureau No. 5, 1892, pp. 52–53.

Suggests that tidal fluctuations may be produced in wells by coastal deformation.

MANDAN, H. G. Note on ebbing and flowing well at Newton Nottage [Glamorganshire, Wales]: Abs. Proc. Geol. Soc. London, 1898, pp. 85–86; Nature, vol. 58, 1898, pp. 45–46.

Shallow well 500 yards from shore ebbs and flows with the tide; lag about three hours.

MALLET, F. R. Ebbing and flowing wells: Nature, vol. 58, 1898, p. 104.

Shallow wells in volcanic ash on Barren Island, Andaman Sea, show tidal fluctuations clearly due to retardation of leakage.

MCCALLIE, S. W. A preliminary report on the artesian-well systems of Georgia: Bull. Geol. Survey Georgia No. 7, 1898, p. 112.

Reports three artesian wells at Tybee Island, near Savannah, Ga., 240 feet deep, one of which is affected by the tide.

MOORE, H. C. A well intermitting inversely with the ebb and flow of the tide: Trans. Woolhope Naturalists Field Club, 1892, pp. 23–24; Jour. Manchester Geol. Soc., vol. 10, 1894, pp. 223–224.

Well at Chepstow, Monmouth, fluctuates inversely with the tide. Shallow pits on Perim Island, Straits of Bab el Mandeb, Red Sea, 20 to 100 yards from shore, are full of fresh water at low tide, empty at high tide; explained on basis of time required for filtration.

PEARSON, Rev. W. Observations on some remarkable wells near the seacoast at Brighthelmstone and other places contiguous. Jour. Nat. Phil. Chem. Arts, vol. 3, 1802, pp. 65–69.

States that shallow wells at Brighton fluctuate with the tide, but with a lag of two hours. He ascribes the fluctuation to retardation of leakage.

PLINY THE ELDER. (Caius Plinius Secundus.) Historia Naturalis, lib. 2, cap. 106: (Pliny's Natural History, Bostock and Riley's translation, vol. 1, 1887, pp. 134–135).

"There is a small island in the sea opposite the river Timavus, containing warm springs which increase and decrease at the same time with the tide of the sea."

RIVIÈRE. Comptes rendus, vol. 9, 1839, p. 553.

Spring at Givre, canton Montiers-les-Maux, fluctuates with tide.

ROBERT, E. Comptes rendus, vol. 14, 1842, pp. 417–418.

Reports that springs near Buder, Olafsen, and Paulsen, Iceland, ebb and flow with the tide.

ROBERTS, ISAAC. On the attractive influence of the sun and moon causing tides . . . in the underground water in porous strata: Rept. Brit. Assoc., 1883, p. 405; see also Proc. Liverpool Geol. Soc., vol. 4, pt. 3, 1881, pp. 233–236.

Reports that in a well sunk in Triassic sandstone in which the water rose 60 feet above sea level, autographic records showed solar and lunar tides. (See p. 69.)

SHELFORD, W. Min. Proc. Inst. Civil Eng., vol. 90, 1887, p. 68.

Describes wells 200 feet deep, on the North Sea, near Louth, Lincolnshire, which fluctuate 3 feet with spring tides.

SINCLAIR, W. F. Ebbing and flowing wells: Nature, vol. 58, 1898, p. 52.

Describes well at Alibag, near Bombay, in sand dunes about 25 yards from high-tide mark, which fluctuated with the tide after heavy rains when the ground water level was high. Tide in well occurred later than that in ocean.

STORER, Dr. JOHN. On an ebbing and flowing stream discovered by boring in the harbor of Bridlington [Yorkshire]: Phil. Trans., vol. 105, pt. 1, 1815, pp. 54–59; Phil. Mag., vol. 45, 1815, pp. 432–436.

S., W. On ebbing and flowing springs: Phil. Mag., vol. 50, 1817, p. 267.

States that wells near Hull under conditions similar to those at Bridlington are not tidal.

TRAUTWINE, J. C., jr. Jour. Franklin Inst., vol. 51, 1901, pp. 193–194.

Explains tidal wells on basis of free discharge in ocean, as from an open tube; changes in pressure at discharge change water level in wells as if they were piezometers along a conduit.

TRIBUS, L. L. Trans. Am. Soc. Civil Eng., vol. 30, 1893, p. 695.

Mentions tidal fluctuations in wells at Pensacola, Fla., 1¼ miles from the shore front, 4 to 6 inches in diameter, and from 60 to 280 feet deep. Water rises 16 to 17 feet above sea level and

fluctuates 6 to 10 inches daily with the tide. He supposes, therefore, that they tap subterranean rivers which have free connection with the ocean. Note: The tides at Pensacola are rather irregular, with a small semidiurnal and large diurnal value, and it is quite possible that a portion of the fluctuation observed is due to barometric and thermometric changes.

VERMEULE, C. C. Water supply for wells: Ann. Rept. New Jersey Geol. Survey for 1898, 1899, p. 163.
States that many wells along the coast of New Jersey show tides corresponding in period, but not in time of occurrence, with the tides of the ocean, and with a smaller range.

WOOD, JAMES G. Jour. Manchester Geog. Soc., vol. 10, 1894, pp. 237-239; Abs. Proc. Geol. Soc. London, 1898, p. 86.
Reports well near that described by H. C. Moore (see above), and suggests that well is fed by water coming along fault, which passes under the river; that at high tide this fault is closed, cutting off supply, and at low tide opens again, allowing an influx; and that therefore well fluctuates inversely with tide. (Note: A simple leakage would, on account of slow propagation of change, explain the phenomena quite as well, and more naturally.)

WOOLMAN, LEWIS. Artesian wells in New Jersey: Ann. Rept. New Jersey Geol. Survey for 1898, 1899, pp. 76, 78, 79.
Records that the height of water in many artesian wells along the New Jersey coast fluctuates with the tide. At Ventor fluctuations were noted in a well 813 feet deep, which had a range of 7¾ to 14¼ inches, and a lag of approximately forty-five minutes. Similarly at Avalon, in a well 925 feet deep, the fluctuation observed had a range of from 10¼ to 15¾ inches.

YOUNG, Rev. G. and J. BIRD. A Geological Survey of the Yorkshire Coast. 4°. Whitby, 1822; 2d ed., 1828.
Ebbing and flowing springs, Bridlington, pp. 22-24; intermittent springs, pp. 27-28.

TIDES IN THE GROUND WATER PRODUCED BY DIRECT SOLAR AND LUNAR ATTRACTION.

The ground water has not an extended level surface like the ocean, where the tides range from nothing to 50 feet, or even the Great Lakes, where the tidal fluctuation is but a few inches. The ground-water table is comparatively level only over areas which are but a fraction of the size of the Great Lakes, and direct ground-water tides would be of extremely small size. It seems quite unlikely, therefore, that the fluctuations in the Maghull (Liverpool) well are due to direct solar and lunar attraction, as Roberts[a] suggests, but, as King[b] has already pointed out, are rather to be ascribed to the action of the ocean tides on the near-by coast.

FLUCTUATIONS DUE TO GEOLOGIC CAUSES.

In regions of abundant rainfall the ground-water table is but a subdued reflection of the surface topography, and any changes in the topography will therefore change the position of the ground-water table. If a stream valley is filled by sedimentation, the ground water is raised over the whole tributary area up to the ground-water divide; if the stream valley is eroded, the water level is in like manner lowered. Similarly, if a lake is produced by a landslip or destroyed by the erosion of its outlet, or the ocean level is changed by orographic movements, the ground-water table likewise is changed. To these broad generalizations certain exceptions are to be mentioned. If a river is intrenched in an impervious layer overlain by porous strata, it is evident that the position of the impervious bed in the bank, when the water level in the river is below it, is the factor which determines the position of the ground-water table. A stream may thus lower its bed without affecting the adjacent ground water. Examples of this kind are found in the Isar at Munich and the Salzach at Salzburg, both of which have deepened their beds in recent times, due to regulating works, without lowering the adjacent ground water, because the deepening was entirely in impervious material.[c]

Solution and deposition by percolating waters may cause a gradual depression or elevation of the water level; solution, by increasing the porosity and consequent rate of flow, will enable quite a quantity of water to escape along certain lines and so lower the water level; deposition, in an opposite way, will raise it.

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[a] Roberts, Isaac, Rept. Brit. Assoc. 1883, 1884, p. 405.
[b] King, Franklin H., Bull. U. S. Weather Bureau No. 5, 1892, p. 54.
[c] Soyka, Penck's Geographische Abhandlungen, vol. 2, pt. 3, Wien, 1888, pp. 60, 63.

In regions where the rainfall is low and the ground-water table is below the level of the rivers changes in topography naturally have little effect, except where the erosion is sufficient to cut the ground-water table. Generally in such regions the rivers contribute to the ground water by seepage, and the amount so contributed becomes small when the conditions are favorable for the deposition of silt with which the rivers plaster up their beds. During flood periods the rivers scour out the silt and again allow the percolation of water.

Earthquakes may produce fluctuations due to several causes: Small fluctuations may result directly from the earth's tremors; a deformation without faulting may produce changes in pressure; and faulting may make new ground-water outlets which will cause the water in neighboring wells to rise or fall according to their relation to the faulting.

Geyser phenomena may produce both periodic and irregular fluctuations of the water level, and Slichter has suggested that the peculiar periodic fluctuations at Warrasino Station, New South Wales (p. 76), may be due to such a cause.

In this connection it may be well to refer to the hypothetical siphon, or Tantalus cup arrangement, which the old philosophers gave as an explanation of intermittent springs,[a] a theory which has survived in Houston's Physical Geography, a work still used in the high schools in some parts of this country.[b] From a geologic standpoint the existence of such a siphon arrangement as this theory postulates may be regarded as almost impossible because of the difficulty of finding an air-tight passage. The fluctuations are now known to be due in many cases to causes not understood at the time this hypothesis was advanced, and in the light of our present knowledge an intermittent spring depending on a natural siphon for its action would be regarded as a most exceptional phenomenon. It would be necessary to do more than prove that a spring or well ebbs and flows to establish the existence of such a siphon.

FLUCTUATIONS PRODUCED BY HUMAN AGENCIES.

EFFECT OF SETTLEMENT, DEFORESTATION, AND CULTIVATION ON THE LEVEL OF WATER IN WELLS.

It is well known that many hillside springs throughout the entire eastern United States which furnished water when the country was first settled are now dry, that large areas of former marsh land are now in cultivation, and that streams on which boats plied in the early days are no longer navigable. The rainfall records do not indicate that there have been any radical climatic changes, and the changes are clearly the result of human occupation.[c]

Part of this is due to the fact that large areas have been artificially drained by tiles, ditches, or absorption pits; beaver dams and other stream obstructions, such as the Great Red River Raft, have been removed, with the consequent drainage of greater or less areas.[d] Some of the hillside springs have merely been buried as the soil washed in from the surrounding lands, while others have been affected by the drainage of the lower lands.

Different kinds of vegetation use different amounts of water[e] and affect the surface

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[a] See Regnault, Père, Phil. Conversations, vol. 2, conversation 6; Dechales, Tract. 17 de Fontibus Naturalibus, etc.; Desaguliers, Rev. J. T., Trans. Phil. Soc. London, No. 384, vol. 33, 1724 (abridged edition Trans. 1665–1800, vol. 7, pp. 39–41); Atwell, Joseph, Trans. Phil. Soc. London, No. 424, vol. 37, 1732 (abridged edition Trans. 1665–1800, vol. 7, pp. 544–555).

[b] For a more recent suggestion of the same theory, see Knightly, T. E., Geol. Mag., n. s., decade 4, vol. 5, 1898, pp. 333–334.

[c] See, in this connection, King, Franklin H., Bull. U. S. Weather Bureau No. 5, 1892, p. 42; Lane, Alfred C., Water-Sup. and Irr. Paper No. 30, U. S. Geol. Survey, 1899, pp. 54–55.

[d] Prof. Paper U. S. Geol. Survey No. 46, 1906.

[e] The literature on the amount of water transpired from plants and evaporated from the earth under different conditions is very extensive, but the results are neither readily comparable nor readily applicable to natural conditions, because of the differing and in many cases unnatural conditions under which these experiments have been tried. For a review of the literature, see Harrington, M. W., Review of forest-meteorology observations, and Fernow, B. E., Relation of forest to water supply; Bull. Bureau of Forestry, U. S. Dept. Agric. No. 7, 1873; Lueger, Otto, Die Wasserversorgung der Städte: Der städtische Tiefbau, Bd. II, pp. 176–177, 196–205, bibliography, pp. 143–161; Wollny, *Ewald, Expt. Station Record*, vol. 4, 1893, pp. 531–533; King, F. H., The Soil, New York, 1895, Drainage *and Irrigation, New York*, 1899.

evaporation in different ways, and a change in the plant covering or crop over large areas may clearly result in a broad elevation or lowering of the water level. Similarly, certain methods of cultivation conserve more moisture than would find its way into the ground under certain natural conditions, while others allow large quantities to flow off the surface. Fertilizers and manures affect the rate of percolation in different ways; some greatly hasten and others retard the percolation of the soil water. The relation of cultivation to the position of the ground water is therefore very complex, and it is clearly possible to have different results on adjacent fields. In regard to the effect of forested areas on percolation it should be pointed out, on the one hand, that (1) a portion of the rain water, varying from 8.5 to 59 per cent[a] of the yearly rainfall, is caught in the crowns of the trees and is evaporated without reaching the ground; (2) the absorption capacity of the forest litter and moss is great, and water can be contributed to the ground water only after this is saturated; while the evaporation from this surface is slow, it is to be considered evaporation from a saturated surface, and the net result may be greater than from a region where the water sinks rapidly into the ground; (3) the old litter or humus is, according to the experiments by Riegler, Ebermeyer, and Wollny, practically impervious, and, while the fresh litter may absorb large quantities of water, the impervious humus or rotted litter prevents the water from reaching the ground water; (4) the roots of the trees in some cases draw from ground water that is entirely out of the reach of ordinary field plants. Moreover, the direct observations of Ototzky[b] and Henry and Tolsky[c] yield the positive result that in Russia and France the level of the ground water is decidedly lower under forests than under cleared land. The results of Ototzky's observations are summarized in the Experiment Station Record in the following words:

> This is a translation from the Russian giving the results of a hydrological survey in the steppes region. The conclusion is reached that, physico-geographical conditions being the same, the level of ground water is lower in forests than in adjacent steppes or in general in neighboring open spaces. The level falls as forests are approached, the fall sometimes being very sudden, and it is more marked in case of old forests than new.

On the other hand, it should be pointed out that the stream flow from forested regions is more constant than from unforested ones,[d] and as this is to be considered as due to ground-water phenomena it indicates a greater percolation.

On the plains, groves and hedgerows by acting as wind breaks tend to elevate the water level by decreasing the surface evaporation.

It is well known to agriculturists that it is possible to cultivate the soil so that the evaporation will be greater than under natural conditions or so that the moisture will be conserved. It is thus possible to either increase or decrease the ground water by cultivation. In the semiarid region of the Middle West, where the rainfall is light, the secret of the so-called "dry or arid farming" is to so prepare the soil as to insure the percolation of all the rain water or of a very large percentage of it, and to prevent its escape by evaporation. To accomplish this various methods of subsoiling, subsurface rolling, and surface mulching, either by pulverizing the soil or by the addition of straw or manure, have been employed, in some cases with marked success. I am informed by Prof. Charles S. Slichter that in western Kansas, where the Campbell system is employed, the ground water has in places been raised several feet by the increased percolation.

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[a] See Bull. Division of Forestry, U. S. Dept. Agric. No. 7, 1893, pp. 100–101, 130–131, and references therein given; also Lueger, Wasserversorgung der Städte, p. 197.

[b] Ototzky, P., Ann. Sci. Agron. 1897, vol. 2, No. 3, pp. 455–477, pls. 2; review, Expt. Station Record, vol. 9, 1898, p. 1041.

[c] Henry, E., and Tolsky, A., Ann. Soc. Agron. 1902, vol. 3, No. 3, pp. 396–422; review, Expt. Station Record, vol. 15, 1903, p. 125.

[d] See Bull. Division of Forestry, U. S. Dept. Agric., No. 7, 1892, pp. 158–170; Manson, Marsden, Comparison of low-water discharge from a timbered with that from a comparatively timberless area: Water-Sup. and Irr. Paper No. 46, U. S. Geol. Survey, 1901, pp. 46–47.

EFFECT OF IRRIGATION.

Irrigation, almost without exception, raises the ground-water level, and in regions where there is no natural ground-water outlet so placed that it furnishes a sufficient natural escape for the underflow, elaborate systems of tiling and pumping are necessary to keep the water level from reaching the surface in the low places and converting them into marshes or alkali flats. Carpenter reports that in the Cache la Poudre Valley, Colorado, the water level has been raised 20 to 40 feet.[a] The effects of irrigation in the King River Valley, California, are shown in Water-Supply and Irrigation Paper No. 58, Pl. XXVI.

On Long Island only limited areas have so far been irrigated, but these bid fair to rapidly increase. On account of the very porous character of the soil and the fact that all the water used must be obtained from the ground water of the region involved, there is no danger of serious raising of the ground-water level; indeed, the net result here of extreme irrigation, which would have to be done by pumping, would be a lowering of the ground-water level to the extent of the added loss by evaporation and plant transpiration. When the water for irrigation is supplied wholly from springs, as it is at one or two points near Flushing, or where supplied from the city waterworks, as at Elmhurst,[b] the result is a local raising of the ground-water level

EFFECT OF DAMS.

In regions where the ground water is tributary to the stream channels the effect of the ponding of streams, except where the material of the bed of the reservoir is entirely impervious, is to raise the ground-water level. As the pond or reservoir is relatively permanent, the ground water generally has time to adjust itself to the new conditions, and an elevation is produced which is persistent as long as the reservoir lasts. Thus on Long Island, where dams were built in all the little streams at an early day, the effect has been to abnormally raise the ground-water level over considerable areas.

In mill ponds of this character the use of the water during the day and the accumulation during the night give rise to a periodic fluctuation of the water in the wells along their banks which tends to accentuate the temperature effect.

In regions where the ground-water table is below the stream, ponding will increase the leakage, though this may naturally check itself in time by the deposition of silt and colloidal material.

EFFECT OF UNDERGROUND WATER-SUPPLY DEVELOPMENTS.

Underground water is developed for water supply in one of four general ways: (1) By subsurface dams, (2) by infiltration galleries, (3) by pumping from single wells or groups of wells, and (4) by flowing wells.

EFFECT OF SUBSURFACE DAMS.

In regions where there are valleys with impervious sides filled with porous material a dam across the valley will pond this underflow and force it to the surface. This has been employed in many regions of the West where dry stream beds with considerable underflow abound. The effect of such a structure on the ground-water level is shown in Water-Supply and Irrigation Paper No. 67, Pls. V, VII.

EFFECT OF INFILTRATION GALLERIES.

Infiltration galleries may either raise or lower the ground-water level. When constructed along the line of contact of a pervious and impervious bed they may act in

[a] Carpenter, L. G., Seepage or return waters from irrigation: Bull. Colorado Expt. Station, No. 33, 1896, p. 4.
[b] Bull. Office Expt. Stations, U. S. Dept. Agric., No. 148, 1904.

a way analogous to a subsurface dam. Where deep in pervious layers they offer a new outlet at a lower level than the natural one, and so depress the water plane. This effect is the same as that in a pumped well, except that here the cone of depression is greatly lengthened in one direction.

EFFECT OF PUMPING.

The first effect of pumping is to develop a more or less symmetrical cone of depression, of which the well is the center. The steepness and slope of the cone depend on such factors as the porosity, rate of flow, rate of pumping, and uniformity of soil. The effect of such a depression in the porous material on Long Island is to lower the water in adjacent wells and drain the near-by ponds and marsh areas.[a]

The effect of this lowering of the water table has a marked effect on the stream flow on Long Island, as is shown by the following table, compiled by L. B. Ward:

Effect of ground-water pumping in diminishing stream flow, from 1873 to 1899, in the old watershed of the Brooklyn waterworks, comparing five-year periods.[a]

Period.	Average annual rainfall.	Average annual rainfall collected, referred to watershed as a whole.		Area of watershed.	Driven-well supply.	
					Expressed as rainfall.	Daily per square mile.
	Inches.	*Per cent.*	*Inches.*	*Square miles.*	*Inches.*	*Gallons.*
1873–1877	43.33	25.07	10.86	52.30	(b)	(b)
1878–1882	41.58	29.60	12.31	55.14	(b)	(b)
1883–1887	43.30	31.60	13.68	64.42	2.95	140,392
1889–1893	45.05	38.43	17.31	65.54	5.85	278,383
1895–1899	43.14	36.32	15.67	66.44	7.76	369,581

Period.	Other pumped sources of supply.		Daily total per square mile derived from all sources in the watershed.	Water collected as stream flow, referred to 50 square miles of watershed.		
	Expressed as rainfall.	Daily per square mile.		Daily per square mile.	Expressed as rainfall.	
					Amount.	Proportion of total.
	Inches.	*Gallons.*	*Gallons.*	*Gallons.*	*Inches.*	*Per cent.*
1873–1877	0.18	8,659	517,206	532,034	11.17	25.79
1878–1882	.99	47,063	585,978	594,310	12.48	30.02
1883–1887	2.30	109,041	651,506	518,071	10.88	25.13
1889–1893	4.17	198,605	824,195	455,153	9.56	21.22
1895–1899	2.74	130,224	745,983	327,122	6.89	15.96

[a] Merchants' Association of New York, The Water Supply of the City of New York, 1900, p. 186.
[b] Began in 1883.

While all pumped wells cause a cone of depression, in regions where the ground water moves rapidly and where the demand does not exceed the supply the recovery is very rapid, as is shown by the figures prepared by W. E. Spear from the records of the Brooklyn water department.[b]

Several points are noteworthy about these diagrams. The water-bearing strata, in the deep and shallow wells, in each case are separated by rather fine material which may usually be called a clay. There is a distinct flow below the clay layer with a velocity, as shown by Slichter, of 6 feet per day, while that immediately above

[a] See discussion in Prof. Paper U. S. Geol. Survey No. 44, 1906, pp. 78–79.
[b] Rept. New York City Commission on Additional Water Supply, 1904, appendix 7, Pls. XI, XII.

the clay layer is but 18 inches. Near the surface the velocity is 3 to 15 feet per day. It is therefore interesting to notice at Agawam, which is essentially a deep-well station, the sympathetic effect of pumping in the lower layer on the water in the upper. There is also an important difference in the depression produced in well No. 11 and well No. 16. This indicates local irregularities in porosity. At Merrick the wells connected to the suction are all shallow but one; the effect of pumping is therefore more marked in the shallow than the deep wells. It is here quite normally greatest in the center well. The recovery after pumping is very rapid in both cases, indicating that the supply is a free one and that the plants have not overdrawn it.

The records for a 181-foot well at the Queens County Water Company pumping station, near Hewlett, N. Y., show regular fluctuations due to pumping (Pl. III, p. 18). This well is 3,000 feet from the pumping station and 2,000 feet from the nearest pumped well, and the records showed fluctuations of such a regular rhythmical character that they were at first thought to represent fluctuations due entirely to temperature changes. Further consideration in connection with the record of pumping from the station shows that the fluctuations are almost wholly due to pumping, although there is perhaps a slight temperature effect involved.

The response of the water level in the deeper wells to changes of pressure at the surface, due to rainfall, tidal, barometric, and thermometric fluctuations, suggests that the removal by pumping of the surface ground water over an artesian stratum will, by relief from load, produce sympathetic fluctuations in deep wells where there is absolutely no connection between the water-bearing strata.

EFFECT OF ARTESIAN-WELL DEVELOPMENTS.

The universal experience in artesian basins has been that after a time the head decreases. This is due to many causes. When the whole basin is affected, it indicates that the outflow or pumping from the wells exceeds the inflow from the porous strata, and a gradual decrease is to be expected until these factors are balanced. A well or group of wells may be influenced by interference from a single well favorably situated. Thus the drilling of a well in which the outflow is many feet below that of near-by wells quickly affects the head of the higher wells. Very often where but a few wells here and there are affected the decrease in head is to be regarded as wholly due to leakage, either on the outside of the casing or by the failure of the casing through corrosion.

All artesian wells are sooner or later pumped, and the effect of the pumping is often to lower the head over wide areas. The diminution of the head in the chalk wells in London during the early part of the nineteenth century is well shown by Clutterbuck.[a]

EFFECT OF LARGE CITIES ON THE WATER LEVEL.

Aside from the general lowering of the water level in cities due to pumpage, another factor tending in the same direction is a decrease of the inflow of rain waters. The mass of buildings, paved streets, and drainage systems absolutely prevent the infiltration of rain water over wide areas. This loss is, however, in part replaced by leakage from the water and sewer systems.

The loading resulting from the placing of large and heavy buildings on small areas will have the same effect as loading due to any natural causes, except that the former is so gradual that in most cases the water has time to escape laterally. It is conceivable, however, that the loading may exceed the rate of outflow and a temporary measurable increase in the artesian head be produced, but this is of such slight value as to be of theoretical rather than practical importance. The effect is practically nothing when the building rests on bed rock, as at New York, and reaches its maxi-

[a] Min. Proc. Inst. Civil Eng., vol. 9, 1850, pl. vi, p. 180.

mum at points like New Orleans, Galveston, and other coast towns underlain by unconsolidated Tertiary and Quaternary beds. A much more readily measurable effect would be produced by large fires, which in a short time would remove a large weight from a limited area. These pressure effects would be noticeable only in wells in which the water is already under artesian head and when the overlying beds have considerable plasticity. They would clearly be greatest in unconsolidated materials and would decrease with the thickness of the strata above the water-bearing layer.

EFFECT PRODUCED BY LOADED FREIGHT TRAINS.

The sensitiveness of the water in wells to any change in load at the surface is strikingly illustrated by the oscillation produced by slowly moving freight trains at Madison, Wis. This is described by King as follows: [a]

> While the self-registering instrument was upon well No. 48, it was observed that there were frequent records of sharp short-period curves shown upon the sheet, which at first were supposed to be the result of accidental jars which the instrument sustained; but the frequency of their occurrence and the fact that they always indicated elevations of the water led to a closer scrutiny and their final association with the movement of trains past the well. On the eight-day instrument these fluctuations are shown as single dashes, but with the one-day form the curve was open. The well in which these disturbances occur is situated about 140 feet from the railroad track and has a depth of 40 feet. It is tubed up with 6-inch iron pipe to the sandstone, 37 feet below the surface, and the water has a mean depth of about 20 feet in it.
>
> The strongest rises in the level of the water are produced by the heavily loaded trains, which move rather slowly. A single engine has never been observed to leave a record, and the rapidly moving passenger trains produce only a slight movement, or none at all, which is recorded by the instrument. The figure shows the curve to be produced by a rapid but gradual rise of the water, which is followed by only a slightly less rapid fall to the normal level, there being nothing oscillatory in character indicated by any of the tracings nor observable to the eye when watching the pen while in motion. The downward movement of the pen usually begins when the engine has passed the well by four or five lengths, and when the pen is watched, it may be seen to start and to descend quite gradually, occupying some seconds in the descent.

This is very similar to the various pressure effects noted above, due to tidal, barometric, and rainfall loading, and to transmitted fluctuations due to variations in local load produced by temperature changes, except that the time of lateral transmission is rather shorter, and it is not clear that the water is under artesian head.

FLUCTUATIONS DUE TO INDETERMINATE CAUSES.

SMALL FLUCTUATIONS.

The extreme susceptibility of the water level in wells to pressure changes would lead one to expect many minute fluctuations; and, indeed, all the well curves show a great number of such fluctuations superposed on the larger fluctuations produced by the dominant element at that point. Many are clearly compound waves of very complex character and represent the resultant of many forces. They emphasize the continued state of unrest of the earth's surface. These fluctuations can be properly studied only with instruments having both a large vertical and time scale, and their elucidation would necessitate corresponding meteorologic instruments of great delicacy.

On the day gages at Hewlett (p. 18) there is a distinct series of minor fluctuations with a well-defined period of about twenty minutes. These greatly resemble the minor oscillations in the tidal curves at many points. [b]

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[a] Bull. U. S. Weather Bureau No. 5, 1892, pp. 67-68.

[b] See Airy, Sir G. B., On the seiches or nontidal undulations of short period at Malta: Phil. Trans. Royal Soc., 1878, pp. 123-138. Dawson, W. Bell, Notes on secondary undulations recorded by self-registering tide gages, Trans. Royal Soc. Canada, sec. 3, 1895, pp. 25-26; Illustrations of remarkable secondary tidal undulations in Nova Scotia, Trans. Royal Soc. Canada, sec. 3, 1899, pp. 23-26. Duff, A. W., Secondary undulations shown by recording tide gages: Trans. Nat. Hist. Soc. New Brunswick, 1897; Am. Jour. Sci., 4th ser., vol. 3, 1897, pp. 406-412. Am. Jour. Sci., 4th ser., vol. 12, 1901, pp. 123-139. Denison, F. Napier, The Great Lakes as a sensitive barometer: Canadian Eng., Oct.-Nov., 1897; Secondary undulations of tide gages, Proc. Can. Inst., n. s., vol. 1, 1897, pp. 28-31; The Great Lakes as a sensitive barometer: Proc. Can. Inst., n. s., vol. 1, 1897, pp. 55-63; The origin of ocean tidal secondary undulations: Proc. Can. Inst. n. s., vol. 1, 1897, pp. 134-135.

The secondary oscillations in the tide curve at Swansea, England, have a time interval of fifteen to twenty minutes; at Malta, twenty-one minutes; and at Sydney, twenty-six minutes; while Denison has observed on Lake Huron oscillations with periods of fourteen, eighteen, twenty-two, and forty-five minutes. As no such secondary tidal oscillations have been observed near Long Island, and as the Hewlett well is at such a distance from the coast that it is not affected by tides 4 feet high, these oscillations are clearly not of transmitted ocean origin. Denison's observations led him to the conclusion that many of the secondary oscillations are due to barometric fluctuations, and the occurrence of these fluctuations in wells must be regarded as strong confirmatory evidence of his conclusion.

Besides these fluctuations with a period of twenty minutes, there are several other minor vibrations with smaller amplitudes and periods; one series seems to have a period of five or six minutes, but is not very sharply defined.

In the wells at Lynbrook (p. 23) minor fluctuations with periods of forty and eighty minutes have been clearly recognized in a mass of still smaller fluctuations.

FLUCTUATIONS AT MILLBURN, N. Y.

Extremely irregular fluctuations with a range of as much as 1 inch were obtained from a well at Millburn, N. Y. (Pl. V, p. 22). These are quite different from any of the other curves obtained and no cause can be assigned for these irregularities. Not the least strange part of the curve is that its general character changes sharply on July 29. (See discussion, pp. 22–23.)

FLUCTUATIONS AT URISINO STATION, NEW SOUTH WALES.

The fluctuations reported by Professor David[a] at Urisino Station, between Wanaaring and Milparinka, in the northwest corner of New South Wales, 200 miles from the ocean, are unique. Two subartesian wells, one 1,680 and the other 2,000 feet deep, in which the water rises to within 15 or 20 feet of the surface, show regular rhythmical pulsations with a range of 4 to 5 feet every two hours. That is, there are here six almost equal "tides" of large size every twenty-four hours. Prof. Charles S. Slichter has suggested the very probable explanation that the fluctuations are due to a sort of periodic geyser phenomena. This is quite competent to produce the fluctuations observed and the high temperature of the water in this basin lends considerable color to the suggestion.

[a] David, T. W. E., Notes on artesian water in New South Wales and Queensland: Jour. and Proc. Royal Soc. New South Wales for 1893, vol. 27, pp. 429–430.

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WATER POWERS OF NORTHERN WISCONSIN

BY

LEONARD S. SMITH

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WATER POWERS OF NORTHERN WISCONSIN.

By L. S. Smith.

INTRODUCTION.

Significance and extent of water-power resources.—Unlike other great natural resources of the State, such as the forest and mineral wealth, the utilization of which means the final destruction of the source of supply, the water-power resources are as certain and eternal as the sunshine. The importance of water powers to a State so remote from coal mines as is Wisconsin is not likely to be overestimated. Unquestionably these powers are destined to exercise a wide influence on the development of the State. So far as known, not a single important river in the State has as yet been made to fully produce its available power. The lower Fox may be said to come the nearest to this, with a total of 31,898 actual horsepower,[a] all produced in the 35 miles between Lake Winnebago and Green Bay. This large water power has caused the district to take high rank as a paper and pulp manufacturing center. Wisconsin, Chippewa, and St. Croix rivers can each be made to produce power equaling and even exceeding that of the lower Fox. Growth in the development of Wisconsin water powers has been very rapid. During the ten years ending in 1900 the gain was 75 per cent. The following figures show the growth during the last thirty years:

Wisconsin water powers developed.

	Horsepower.
1870	33,700
1880	45,300
1890	56,700
1900	99,000

The annual saving represented by this power over the cost of an equivalent amount of steam power, computed at $20 per horsepower, reaches the sum of nearly $2,000,000.

Sources of information.—Judging from the scant literature descriptive of Wisconsin water powers, but little attention has been directed in the past to this great natural resource of the State. The longest and most accurate description is contained in the Tenth Census of the United States. In Geology of Wisconsin, volume 3, 1880, will be found good detailed descriptions of the Lake Superior rivers from the standpoint of a geologist. Very reliable information regarding the upper headwaters of the larger rivers is given in the reports of the Chief of Engineers, U. S. Army, for the years 1879–1883, inclusive, to which frequent reference is herein made. This work of surveying reservoir sites involved the running of many hundred miles of levels, thus securing numerous water levels on lakes and rivers. The maps of these surveys were never published, but copies of the originals have been obtained, and no pains or expense has been spared to preserve and present these data. A fourth source of information, and a most welcome one, both because of its intrinsic value and because it marks the beginning of a rational and systematic study of Wisconsin water powers, is the detailed survey of part of Chippewa River and the daily discharge records of

[a] Rept. Chief Eng. U. S. Army, 1897, p. 2737.

many important water-power rivers carried on by the United States Geological Survey during the years 1903, 1904, and 1905.[a]

Finally, the data here presented would have lacked much of whatever value and completeness they may have had it not been for the generous support of hydraulic engineers and mill owners.

After exhausting all possible sources of information by correspondence, however, it was found that many points of importance could be cleared up only by a personal visit to the field. In this manner visits were made to St. Croix River at Taylors Falls; to Apple and Willow rivers; to Eau Claire and Chippewa Falls, on Chippewa River; to Black River Falls and Neillsville, on Black River; to Grand Rapids, Stevens Point, Tomahawk, and Rhinelander, on Wisconsin River, and to Oshkosh, Appleton, Menasha, Kaukauna, and Depere, on Fox River.

The importance of these water-power resources to the development of the State would certainly justify it in cooperating financially with the United States Geological Survey by extending the investigation to include hypsometric surveys of the important rivers, especially in the region now undeveloped.

PHYSICAL GEOGRAPHY OF NORTHERN WISCONSIN.

GEOLOGY.[b]

The rock formations of northern Wisconsin readily fall into three classes—the pre-Cambrian crystalline rocks, the Paleozoic rocks, and the Glacial drift. The pre-Cambrian and Paleozoic formations are adjacent to one another, but the loose Glacial drift is distributed irregularly over all the hard-rock formations of the region.

PRE-CAMBRIAN ROCKS.

The pre-Cambrian crystalline rocks consist of various kinds of igneous rocks, such as greenstone or trap rocks, granite, diorite, rhyolite, schists, and gneisses, and varieties of metamorphosed sedimentary rocks, such as quartzite, slate, limestone, conglomerate ferruginous rocks, slate, and schists. The rocks here classed as pre-Cambrian include all those often referred to as the Laurentian (Archean), Huronian, and Keweenawan series. The various kinds of crystalline rocks generally stand on edge, trend in various directions, and form irregular belts and areas throughout the region.

The area of crystalline rocks covers the principal part of northern Wisconsin. Its northern boundary is approximately parallel to and very near the adjacent shore of Lake Superior; on the west it projects irregularly into Minnesota; on the south it extends to the central part of the State, and on the east it reaches within 25 to 40 miles of Green Bay.

The pre-Cambrian region is the highest portion of the State, and in these crystalline highlands the large rivers have their source and flow outward in all directions. The crystalline rocks are generally hard. They do not everywhere have this character, however, and the lack of uniformity causes much irregularity in the surface features. High, rounded knobs of hard granite and quartzite dot the surface of the region, and the abrupt variations in the character of the rock along the river valleys have caused the formation of numerous rapids and waterfalls. The slope of the pre-Cambrian region is relatively steep on the Lake Superior side and comparatively gentle toward the east, south, and west.

PALEOZOIC ROCKS.

The Paleozoic rocks consist of alternating formations of comparatively incoherent, friable sandstone and hard, compact limestone lying unconformably upon the upturned edges of the crystalline rocks and dipping slightly toward the north, east, south, and

[a] The Wisconsin legislature of 1905 appropriated $2,500 for the purpose of surveying the water powers of the State in cooperation with the United States Geological Survey, which has set aside an equal amount for this purpose. In the fall of 1905 Wisconsin, Black, and Flambeau rivers were surveyed. This work is in charge of Leonard S. Smith.

[b] Prepared by S. Weidman, State geologist of Wisconsin.

west—the dip thus being away from the broad central core of the pre-Cambrian region. The Paleozoic rocks of northern Wisconsin include the following formations, named from the base upward: (1) Cambrian ("Potsdam") sandstone, (2) "Lower Magnesian" limestone, (3) St. Peter sandstone, and (4) "Trenton" limestone.

The Cambrian sandstone is by far the most abundant Paleozoic rock of the region. Along the shore of Lake Superior, where it is generally called the Lake Superior sandstone, it forms a strip less than a mile in width at the Michigan boundary, increasing to 15 miles in width at the Minnesota boundary. For variable distances of 15 to 40 miles about the broad central area of the pre-Cambrian to the west, south, and east, the Cambrian is the principal surface rock. It is only adjacent to the shore of Green Bay on the east and in St. Croix and Pierce counties on the west that limestone and sandstone later than the Cambrian occur to any notable extent.

The surface features of the Cambrian sandstone district are mainly broad valley bottoms, dotted here and there with a few pinnacles of hard sand rock. In the region of the limestone, however, the valleys are generally sharp and narrow, and the uplands constitute the main portion of the landscape. The hills and sharp ravines in the limestone district are in sharp contrast with the broad, graded valley bottoms of the sandstone district.

GLACIAL DRIFT.

The Glacial drift consists of a loose, incoherent mass of bowlders, gravel, sand, and clay. In some places the coarse drift is abundant, while in other places clays and sand prevail. The drift has a very irregular thickness throughout the area. It was deposited upon the older crystalline and Paleozoic rocks during the several successive glaciations in Wisconsin and the adjacent region.

Drift in variable quantity occurs throughout northern Wisconsin, being very abundant in the northeastern, northern, and northwestern parts of the region, while in a very irregular but considerable area in the southwestern part the drift is very thin.

The surface of a large part of the drift-covered region is very irregular and uneven, and consists of hills and ridges alternating with basins, swamps, and lakes. In some places the drift covering completely obliterates the topographic features of the crystalline and Paleozoic rocks; in other places it only modifies the older topography. On the whole, however, the glaciation of the region exerted a considerable influence on the distribution of the drainage lines and in shaping the minor inequalities of the land surface. The drift region, from the topographic point of view, may be divided into two general districts—one covered by the older drift series and the other by the later drift. In the district of the older drift, the southwestern part of northern Wisconsin, there are no lakes or ponds, and swamps are very rare. Here the topography is mature and the land has good surface drainage. In the district of the later drift, however, which includes the main portion of northern Wisconsin, the glacial deposits are abundant; ridges and hills of bowldery material occur, and lakes, swamps, and sags are common. In this district, therefore, the surface drainage is often very poor and large amounts of water are held in swamps and ponds. Here, also, there are marked differences in the surface features prevailing over large parts of the district. Along its border is the terminal moraine, often called the "kettle moraine," having a width ranging from 3 or 4 to 20 miles and consisting of numerous drift hills and ridges closely associated with sags, lakes, and ponds. This terminal moraine extends across the entire continent. In crossing this portion of the State it turns north a few miles east of Grand Rapids, thence extends to Antigo, thence in a sinuous belt westward to Barron County, and thence southwest into Minnesota. Back of this terminal moraine—that is, to the east and north—are similar belts known as "recessional moraines," separated one from another by broad areas having the general features of the hard rocks beneath. Between the moraine belts are broad tracts of sandy land, called "barrens," which cover considerable portions of the northwestern part of the State. Along Lake Superior is a broad belt of nearly flat clay land which may be mentioned, though it has no influence on the distribution of the water powers of the region.

TOPOGRAPHY.

The abundant water-power resources of Wisconsin are the result of its unique topography. A wide and comparatively flat highland crosses the northern part of the State. This divide varies in elevation from 1,900 feet in the eastern part to 1,000 feet in the western part, and extends to within 30 miles of Lake Superior. From it the rivers descend radially in all directions except eastward. Owing to the fact that Lakes Superior and Michigan bound the State on the north and east, while Mississippi River forms the southwestern and the larger part of the western boundary, all the rivers must needs find a low trough into which to discharge, and that at a short distance from their source. This condition results in a rapid fall and large water powers.

About 9 per cent of the total area considered belongs to the abrupt Lake Superior watershed and the remainder to the broad southeast, south, and southwest slopes. The divides between the rivers which drain this southern slope are almost imperceptible, in some cases being entirely lost in labyrinths of lakes and swamps.

Hills over 300 feet in height are rare. A few "mounds," or isolated steep hills with extremely narrow bases, rise out of the sandy plains of Jackson and Clark counties, and a few larger, more massive hills, one 1,940 feet above the sea, occur in the valleys of the larger rivers, besides the low, broad hills which form the crests of the Penokee and Copper ranges. These hilly tracts do not cover over 5 per cent of the total area, while about 45 per cent is level upland and about 50 per cent is rolling country, of which a considerable portion is steeply rolling "kettle" or "pot-hole" land.[a]

The surface features are discussed elsewhere, under the head of "Geology," and also in connection with the drainage of each river.

HYDROGRAPHY.

St. Croix, Chippewa, Black, and Wisconsin rivers drain 70 per cent of the northern half of the State, an area nearly equal to that of the State of Maine. The Lake Superior rivers drain only 9.3 per cent and those flowing into Green Bay the remaining 20.7 per cent.

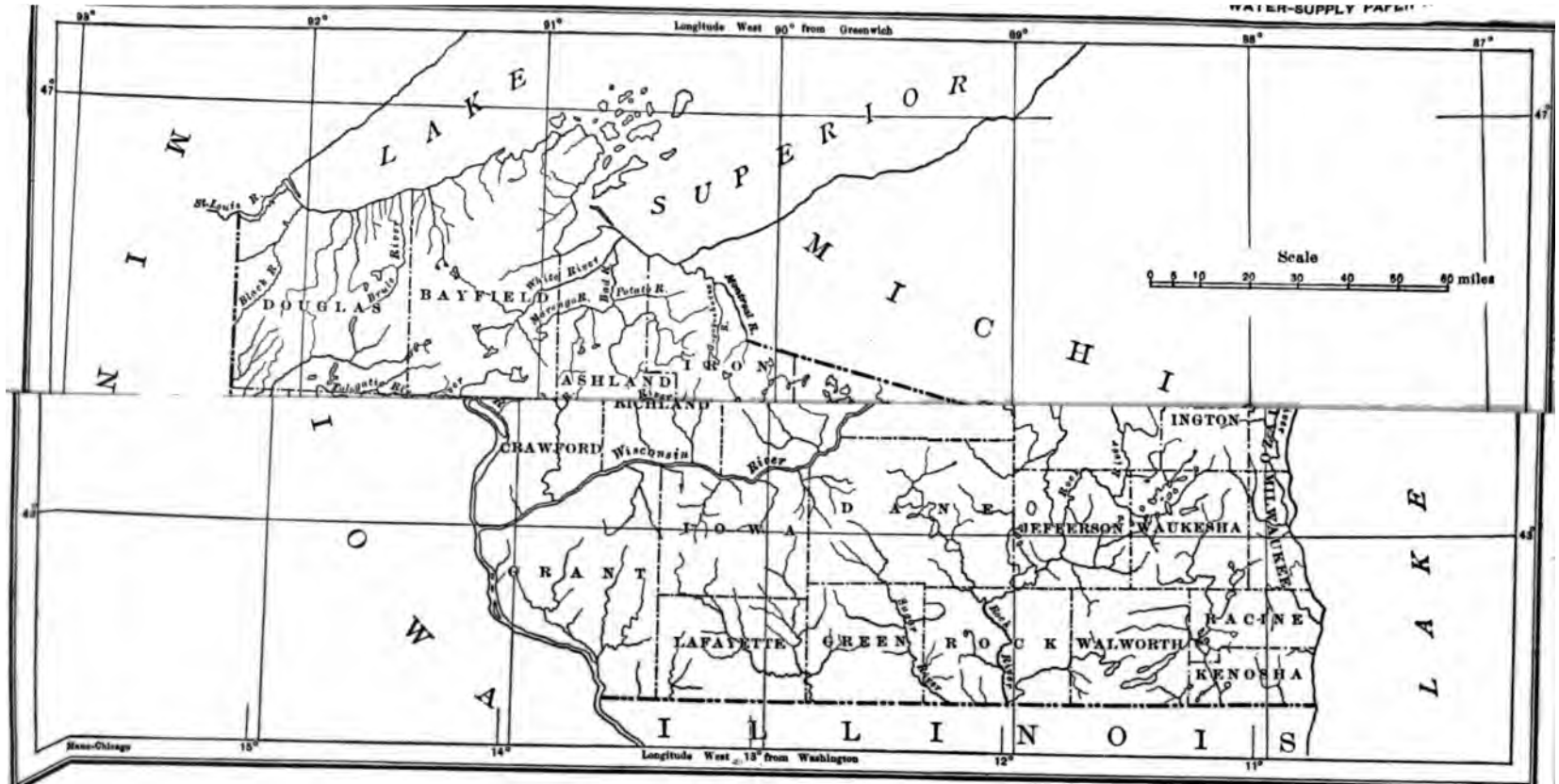
In general, each of the important rivers may be divided into three divisions, differing widely in physical characteristics. First, the headwaters, marked by sluggish streams with low divides, fed by numerous and extensive swamps and lakes, frequently so interlaced that it is impossible to trace out the river divides. Here many of the lakes have dam sites forming natural reservoirs for the river below. Bowlder rapids are here of frequent occurrence. Second, a stretch of maximum descent along the center reach of the river, abounding in numerous falls and long stretches of rapids. This part of the river is always in the region of the pre-Cambrian crystalline rocks, the southern border of which marks the lower limit of the rapids.[b] Third, the lower portion of the course, where for a distance of about 50 miles the river flows through sandstone and limestone, the descent being very slight. This region is, therefore, devoid of water power. In fact, the United States Government has improved the larger rivers along this reach for the purpose of navigation without the use of locks.

As compared with the upper Mississippi basin in Minnesota, the area under discussion may be said to have a steeper grade, the middle portion, containing the main water powers, having an average fall of 3 to 8 feet to the mile. Because of the storage effect of the lakes and swamps, the low-water run-off is as high as from 0.3 to 0.8 second-foot per square mile of drainage area. Probably about a third of the total rainfall finds its way into the streams.

The general use and control of these northern rivers for logging purposes in the past tended to decrease the value of the water powers by withholding the water at times when most needed. All logging on rivers is fast disappearing. Indeed, on many rivers, like the Wisconsin, it has practically given way entirely to railroad transportation. This leaves the rivers free for the permanent development of their water powers. The effect on

[a] Roth, Filibert, Forestry Conditions of Northern Wisconsin: Bull. Wis. Geol. and Nat. Hist. Survey, No. 1, 1898, pp. 2-3.

[b] The only important exception to this rule is on Wisconsin River at Kilbourn, where the river descends rapidly about 16 feet in the dalles of the Potsdam sandstone.



DRAINAGE MAP OF WISCONSIN.

e stage of water which these dams have had in the past suggests their enlargement, tension, and systematic operation for the sole purpose of increasing the low-water flow. The United States engineers have surveyed 32 large reservoirs in Wisconsin and have nstructed five such reservoirs in Minnesota. The total capacities of the proposed Wisnsin reservoirs are as follows:[a]

Storage capacity of proposed reservoirs in Wisconsin.

River.	Area of overflowed lands.	Storage capacity.
	Acres.	*Cubic feet.*
. Croix	[b] 102,092	34,334,000,000
ippewa	Not given.	25,239,000,000
isconsin	25,832	19,557,000,000
		79,130,000,000

The intelligent operation of even a part of these reservoirs would have a marked effect steadying the river discharge. This point will be separately discussed in connection ith the several rivers. It may be remarked here that nature, by providing numerous wamps and upward of 1,400 lakes for this region, has accomplished unaided a decided egulation of the water supply.

The availability of these water powers varies greatly on the different rivers, or even on arts of the same river. Those on Wisconsin River, for example, are all reached by the hicago, Milwaukee and St. Paul Railway, which parallels the river for 100 miles, and by ther railroads at certain points. The powers on the lower Chippewa are likewise available; ut as yet, because of the small population, the railroads have not built generally into he upper part of the region. The rapid opening up of farms now in progress will soon ring a demand for better transportation.

The present bulletin discusses the water powers of the northern rivers, for the reason hat these powers are the least known and least developed.

SOILS.[c]

The soils of northern Wisconsin may be grouped into seven readily recognized classes.

Sandy soils are found in regions known as flood plains, and owe their origin to the sorting ction of flowing water as it issued from the melting ice. The two largest areas of this ype are found in central Wisconsin east of Black River and in the northwestern part of he State. These soils are so coarse and open that nearly all the rain soaks into the ground, appearing later at lower levels as springs.

Sandy loams cover a much broader area than the sandy soils, being roughly coincident distribution with the Potsdam sandstone, from which they have in large part been erived.

Prairie loam is a light, open soil, more closely allied to those described above than to he following ones. It is usually underlain by from 3 to 5 feet of coarse, open gravel. In orthern Wisconsin the largest area of this type is found in St. Croix County.

Clayey loam is finer and contains more clay than the soils already described. Such a il has a great capacity for holding water. "The area of northern Wisconsin covered y this type of soil is larger than that occupied by any other variety."

Loamy clay is still heavier and more clayey than the last, with smaller particles. There re three considerable areas of the soil in this region.

Red clay soil is the most peculiar, the finest grained, and heaviest in the State. It is ractically impervious to water. Its areas border Lakes Superior and Michigan.

[a] Rept. Chief. Eng. U. S. Army, 1880.
[b] Including 27,406 acres in Minnesota.
[c] Condensed from F. H. King's description in Northern Wisconsin Handbook.

Swamp soil includes all swamp and marsh land soils. While few very large single areas are covered by these soils, the aggregate amount is probably not less than 1,000,000 to 1,500,000 acres. Some of these lands are now covered by a growth of white cedar, others with tamarack and spruce, the latter being usually found on the borders of both tamarack and cedar swamps, while still others are simply sedge marshes, some of which are yearly cut for hay. In many other swamp areas fires have killed the trees, causing all the small anchoring roots to die and decay, so that the winds have overturned nearly every tree.

Many of the northern swamps are underlain by vast beds of peat, while all have a thick covering of moss and humus. Both these factors play an important part in delaying the water in its journey to the streams.

FOREST CONDITIONS.

"Northern Wisconsin in its primeval state was a vast forest of magnificent timber." This could be said to-day of large areas. The central portion of this region includes mixed forest in which, though the pine has nearly all been cut, there still remain over 5,000 feet of hard wood and hemlock per acre, besides other timber equally valuable. The total area covered by forests of this grade amounts to 8,000 square miles, about the same as that of the State of Massachusetts.

Mr. E. T. Sweet[a] enumerates 34 different kinds of trees which he found on the Lake Superior slope alone. Additional species found on the southern slope would increase this number considerably.

The lumberman's labors were first directed to getting out the pine, both because of its high value and because of the fact that he could float it downstream to market. This industry, including the manufacture into lumber, had an invested capital in 1900 of $100,168,000 and turned out a product valued at $81,983,000.[b] This easily places it as the most important industry of the State. Only two other States exceeded this in 1900. In the same year, according to the United States Census report, Wisconsin was the leading State of the Union in lumber and timber products, their total value being $58,000,000. The amount of pine timber is limited and already its production is waning. Its place is being taken, to a large extent, by hard-wood timber, by cedar posts and poles, and by hemlock lumber and bark. The changes wrought annually by the lumberman's ax and the succeeding forest fires are very considerable. The recent appointment of a State forestry commission promises much for the protection and fostering care of these great interests.

The once popular belief that this northern area was worthless after the loss of its timber has given way in the past ten years to a general confidence in its agricultural possibilities. This is amply evidenced by the rapidity with which these lands are being opened up by farmers and by their rapid appreciation in market value. In 1895 only 7 per cent of the 18,000,000 acres of the northern half of Wisconsin was cultivated. This region has furnished 85,000,000,000 feet B. M. of pine lumber alone in the past sixty years. The gradual clearing of the timber has doubtless had an effect on the run-off of the rivers. Under the changing conditions the rainfall will be less absorbed by the soil and will get to the streams in a shorter period. This is especially true of the swamps, where the fires have burned the thick humus and moss which formerly delayed the passage of the water to the lakes and rivers. It is only fair, however, to call attention to the fact that large areas of the original timber consumed by forest fires have been replaced by a second growth of both hard and soft timber, much of it in the form of dense thickets, which shade and protect the ground more effectually even than the original forest.

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[a] Geol. Wisconsin, vol. 3, 1880, p. 328.

[b] U. S. Census, 1900, pt. 1, p. 293.

CLIMATIC CONDITIONS.

TEMPERATURE.

The climate of this region is characterized by a large amount of sunshine, with high emperatures in summer and extreme cold, deep snows, and clear skies in winter. The ummer heat and winter cold are generally tempered by the influence of the bordering akes. Lakes Superior and Michigan cover an area of over 54,000 square miles and never reeze over in winter. Although the prevailing wind is from some westerly quarter, this is so frequently broken up by the passing of storm centers from the lakes that both the temperature and the humidity of the air are affected by these great bodies of water. Wisconsin rivers are generally frozen over between December 1 and March 30. The following table gives the highest and lowest temperatures for each month of the year for the twelve years ending 1883 at places in or adjacent to this region:

Highest and lowest temperatures for each month of the year for the twelve years ending 1883.[a]

Locality.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept	Oct.	Nov.	Dec.
Duluth:												
Maximum	51	57	62	75	91	92	99	93	90	78	65	51
Minimum	−38	−34	−26	3	26	36	46	45	30	8	−29	−34
Marquette:												
Maximum	56	69	70	81	92	95	100	96	97	87	66	59
Minimum	−26	−27	−14	3	22	31	40.3	39.7	28	18	− 9	−20
Escanaba:												
Maximum	45	52	57	65	83	88	92	89	84	75	61	48
Minimum	−26	−32	−20	2	20	34	42	38	26	17	9	−23
Alpena:												
Maximum	52	58	66	72	91	97	97	92	92	83	63	56
Minimum	−27	−27	−14	2	22	33.5	45	40	29.3	22	− 4	−15
St. Paul:												
Maximum	49	59	68	82	94	94	100	98	94	87	72	56
Minimum	−31	−32	−22	7	24	39	46	43	30	15	−24	−30
La Crosse:												
Maximum	59	65	72	83	96	98	101	96	92	84	70	60
Minimum	−43	−34	23	10	29	40	52	44	31	18	−21	−37

[a] King, F. H., Northern Wisconsin Handbook, 1896.

In connection with the sudden lowering of the winter temperature, a most interesting phenomenon was observed on St. Croix River by United States engineers in the early winter of 1882:[a]

This was the apparently close relation between the temperature and the mean velocity and discharge of the stream, the stand of the water being at the same time nearly constant. In the early winter it was found that each cold wave which increased the thickness of the ice about one-tenth of a foot at a time was accompanied by a great falling off of the discharge, to be followed by a partial recovery during the next few days, the same phenomenon recurring with great regularity at each cold wave. The recovery of discharge being in each case only partial, the gradual tendency was downward until the apparent minimum was reached, when there was no appreciable change for several weeks.

PRECIPITATION.

The average rainfall for twenty-five years over the entire State is close to 32.3 inches, distributed by seasons as follows: Winter, 4.7 inches; spring, 7.6 inches; summer, 11.7 inches; autumn, 8.3 inches. If the rainfall of the northern half alone be considered, these figures would probably need to be slightly increased. It is worthy of note that 60 per

[a] Rept. Chief Eng. U. S. Army, 1883, p. 1470.

cent of the rainfall comes in the summer and autumn months, while the least fall is during the winter months. December, January, and February are the months of minimum run-off, both because of smaller precipitation and because of low temperatures and resulting deep frosts.

In general, it may be said that the precipitation in Wisconsin exceeds that of Minnesota and Michigan and about equals that of Iowa.

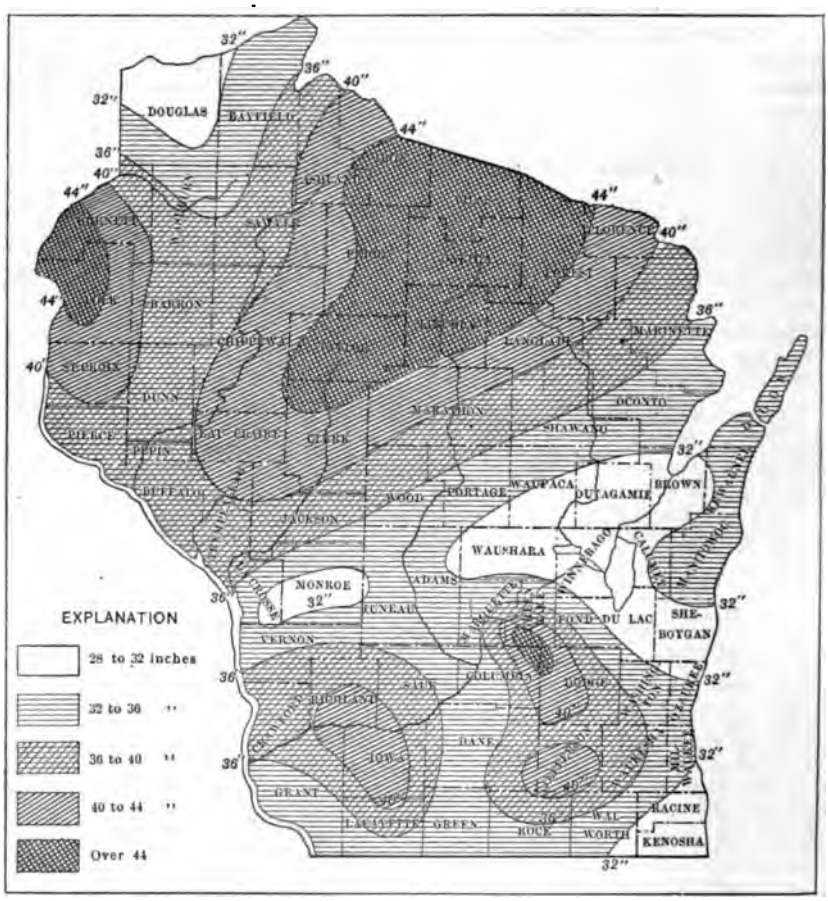

FIG. 1.—Rainfall map of Wisconsin.

Because of its bearing on the run-off of the various river systems, whose discharge measurements for 1903 and 1904 are herein given, the precipitation map shown in fig. 1 has been prepared. It will be noted that the heaviest rainfall occurred in the northern part of the State, averaging about 40 inches.

The following table shows some details of the distribution of rainfall by months:

Average precipitation at five stations in Wisconsin for twenty years.[a]

Detail.	Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
PERCENTAGES.													
Distribution	100	4.9	4.3	6.1	7.2	10.5	13.8	12.1	11.0	12.0	7.9	5.5	4.9
Classification of days:													
On which rain fell—													
Mean	41.2	43.0	41.9	40.4	40.6	43.7	48.1	41.1	38.2	41.7	36.1	39.3	43.5
Maximum	56.5	77.4	79.2	59.4	59.3	67.5	70.0	66.2	60.6	70.0	60.8	71.0	79.6
Minimum	27.0	18.7	11.3	19.3	21.9	20.7	30.6	17.4	21.3	15.9	12.8	14.9	19.3
Without rain	58.7	57.9	58.1	60.2	59.6	56.3	51.9	58.9	61.8	57.6	63.9	60.7	56.5
Trace to 0.25′	31.4	41.1	36.8	32.4	30.6	30.6	30.9	27.6	25.7	28.4	26.2	32.1	37.7
0.25′ to 0.50′	5.0	3.3	3.4	4.1	5.8	5.3	7.5	5.8	5.3	6.3	4.8	3.9	3.7
0.50′ to 1.00′	3.4	1.4	1.5	2.8	3.0	4.4	5.7	4.9	4.6	4.6	3.6	2.5	1.7
1.00′ to 2.00′	1.4	.3	.3	.4	1.2	1.8	3.2	2.0	1.9	2.6	1.6	.7	.4
2.00′ to 3.00′	.2	.2	.....	.1	.3	.4	.7	.7	.6	.3	.....	.....	.....
3.00′ to 5.00′	.1	.....	.....	.....	.....	.1	.....	.2	.1	.2	.....	.....	.....
Over 5′	.2	.....	.....	.....	.....	.....	.....	.....	.....	.2	.....	.....	.....
NUMBER OF DAYS.													
Greatest consecutive—													
With rain	26	12	16	12	13	13	11	13	15	13	19	14	14
Without rain	14	9	9	8	8	9	13	8	8	8	8	9	13
INCHES OF RAIN.													
Heaviest in 1 day	7.23	2.6	1.8	2.1	2.9	3.1	2.9	4.5	3.9	5.6	7.23	1.8	1.5

[a] Moore, W. L., Rainfall of the United States: Bull. D, U. S. Dept. Agriculture.

The amount of precipitation is fairly constant for the winter and a portion of the fall and spring months, but varies considerably in the summer months.

Exceptionally dry periods occur about once in fifty years, when the average for three consecutive years is 22 inches and the least for one year is 13.5 to 20.5 inches. Dry periods occur once in twenty-five years, when the average for three consecutive years is 24.2 inches and the least for one year is 20.3 inches. Moderately dry periods occur once in ten years. The exceptionally dry periods are preceded by an exceptionally wet period, when the annual precipitation has been as high as 50 inches. This is followed by a period of moderately heavy rainfall, with a maximum of 45 inches. The last exceptionally dry period occurred in 1894 to 1896.[a]

The year 1903 had a moderately heavy rainfall. If the above cycle can be depended on, the next period of maximum rainfall may be expected about the year 1908.

Fig. 2 shows the progressive averages of the precipitation at Milwaukee for the past seventy years, computed by the formula—[b]

$$\frac{a+4b+6c+4d+e}{16}=c',$$

where c represents the rainfall of the year in question and b and a stand for the rainfall in the two years preceding, while d and e represent the rainfall of the following two years.

[a] Kirchoffer, W. G., master's thesis.
[b] After Blandford. See Bull. D, U. S. Weather Bureau.

This curve makes clearer the nature of the rainfall cycle.

In the following table are shown the long-term precipitation records of four t

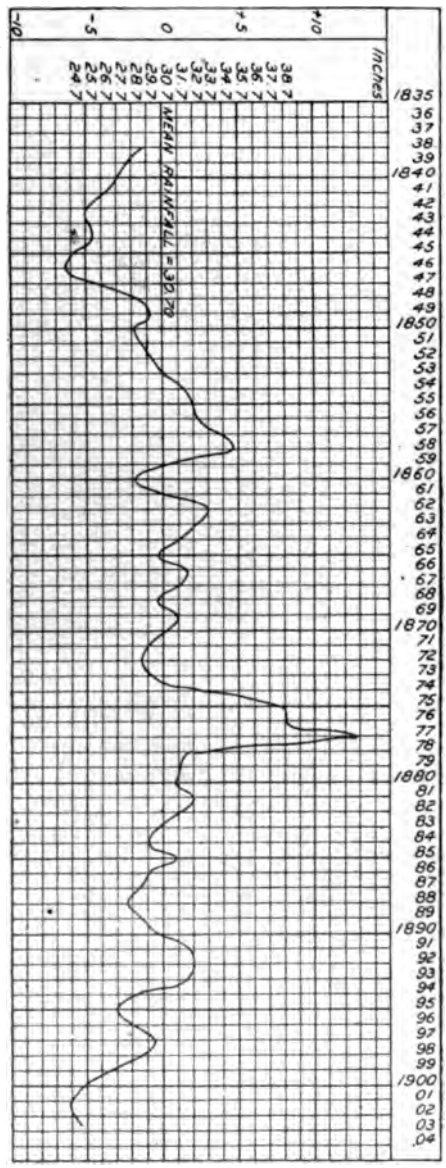

FIG. 2.—Chart showing rainfall at Milwaukee, 1837-1904.

stations in this general region. The rainfall at Milwaukee appears to be consider less than the average of the State.

pitation at Milwaukee and Embarrass, Wis., and Duluth and St. Paul, Minn.

	Milwaukee.	Embarrass.	Duluth.	St. Paul.	Year.	Milwaukee.	Embarrass.	Duluth.	St. Paul.
.....	20.5	.....	.....	.....	1875	35.6	43.9	27.0	30.7
.....	25.3	.....	.....	.....	1876	50.4	48.9	32.3	23.6
.....	22.4	.....	.....	.....	1877	46.2	34.4	34.3	28.7
.....	33.5	.....	.....	.....	1878	38.3	37.6	28.1	22.6
.....	31.1	.....	.....	.....	1879	24.9	41.6	45.3	32.5
.....	26.4	.....	.....	.....	1880	30.0	49.8	38.2	29.8
.....	30.4	.....	.....	.....	1881	39.1	57.4	37.6	39.2
.....	29.3	.....	.....	.....	1882	28.4	49.0	38.0	23.1
.....	30.0	.....	.....	.....	1883	29.5	42.2	23.2	26.5
.....	31.7	.....	.....	.....	1884	30.6	62.1	35.8	26.1
.....	36.0	.....	.....	.....	1885	32.6	42.6	20.0	25.3
.....	29.0	.....	.....	.....	1886	31.5	45.4	33.3	22.9
.....	30.9	.....	.....	.....	1887	30.5	43.6	28.5	25.9
.....	44.9	.....	.....	.....	1888	23.5	43.9	27.3	25.8
.....	28.9	.....	.....	29.1	1889	31.7	33.8	32.0	17.1
.....	24.0	.....	.....	34.2	1890	30.1	44.0	24.1	23.5
.....	31.9	.....	27.7	30.5	1891	29.8	41.2	29.5	21.8
.....	38.3	.....	35.4	34.5	1892	35.0	44.9	28.5	32.6
.....	31.8	.....	22.8	15.7	1893	32.9	23.1	23.3	26.0
.....	27.8	28.9	17.8	14.9	1894	27.8	.....	31.7	25.8
.....	30.1	36.3	20.9	38.1	1895	24.9	16.7	22.3	24.3
.....	34.0	34.5	30.6	27.9	1896	29.0	32.4	27.1	34.7
.....	24.6	29.0	25.7	33.6	1897	31.0	25.3	30.9	30.5
.....	29.4	38.8	.....	30.7	1898	32.4	28.1	19.7	25.3
.....	37.8	39.3	.....	32.2	1899	22.8	27.8	30.5	27.5
.....	26.6	41.9	.....	32.1	1900	30.1	.....	23.1	34.2
.....	32.0	37.7	31.2	30.7	1901	18.1	.....	26.7	25.8
.....	26.2	28.5	30.1	29.6	1902	28.6	.....	26.1	31.8
.....	30.6	35.0	38.8	34.6	1903	23.4	.....	28.0	37.9
.....	30.8	31.0	36.5	35.5	1904	29.9	.....	24.5	34.1

FOX RIVER SYSTEM.

DRAINAGE.

innebago, the largest inland lake in Wisconsin, divides Fox River into two rad-
erent sections, the upper and the lower Fox. The upper river approaches from
east to within about a mile of Wisconsin River at Portage, then turns to the north-
s course to Lake Winnebago. It winds, with low banks, through broad savannas
ly a gentle slope, passing a total distance of 25 miles through three long lakes
ching Lake Winnebago.

e, Buffalo Lake, and Lake Puckaway have been caused by the deposits of affluents which
ream has not been able to wash away, plainly indicating that the present upper Fox did not
urse, for it has not even the power to keep itself free, but instead is filling up. Lake Butte
and Lake Winnebago are depressions which the present tendency is to fill up.[a]

Varren's hypotheses for these peculiar conditions have been widely accepted, and
eresting that they are here given:

only to suppose that all the waters of Lake Winnebago basin (including that of the upper
rly drained to Wisconsin River; that a slow change of level in this region elevated the south-
rt and depressed the northeastern part till a large lake was formed, which finally overflowed,
e course of the lower Fox. This explains the present doubling back in the course of the

[a] Warren, G. K., Rept. on Wisconsin and Fox rivers, 1876.

upper Fox and tributaries, and it accounts for the close relation and yet opposite courses of Fox and Wisconsin rivers. As the level changed the erosion at the outlet could not keep pace with it and so prevent a lake forming, because a granite ridge lies near the surface between the Wisconsin and Buffalo Lake. When the lower Fox outlet formed the loose material covering the rocks rapidly gave way and lowered the lake level down to the rock, which now (1875) keeps it to its present level. The period of this change was post-Glacial, because this alluvial terrace is free from Glacial drift, which it could not have been if formed before in a region like this, surrounded by Glacial drift deposit.

UPPER FOX.

Fox River descends only 40.4 feet in the 95.5 miles between Portage and Lake Winnebago—an average fall of less than 0.5 foot to the mile.

The following table shows the river profile in detail as given by United States engineers:

Profile of Fox River from Lake Winnebago (Oshkosh) to Portage lock (Fort Winnebago).

Station.	Distance— From Lake Winnebago.	Distance— Between points.	Elevation above sea level.	Descent between points. Total.	Descent between points. Per mile
	Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
Lake Winnebago	0	.....	746.1	.....	
Eureka lock, crest	24.6	24.6	748.8	2.7	
Berlin lock, crest	32.9	8.3	750.6	1.8	
White River lock, crest	33.9	10.0	755.7	5.1	
Princeton lock, crest (Lake Puckawa)	43.3	9.4	760.2	9.4	0.42
Grand River lock, crest	64.0	20.7	763.9	3.7	
Montello lock, crest (Lake Buffalo)	67.3	3.3	768.9	5.0	
Governor Bend lock, crest	91.4	24.1	774.7	5.8	
Fort Winnebago lock (Portage)	95.5	4.1	781.6	6.9	

Fox River has been improved for navigation by the Federal Government along this entire distance by the building of 10 locks, but the slight fall gives few opportunities for water power.

The first dam on the Fox is at Pardeeville, where a head of 14 feet is available. Wisconsin River is about 10 feet above Fox River at Portage, and this fall could be utilized by a dam near the Fort Winnebago lock. A considerable quantity of water could be discharged through the canal with safety.

At Montello, 28 miles below, a turbine is installed under a head of 3 feet, developing power for a gristmill. No developed power is in use on the river below this point.

The three principal tributaries of the upper Fox have a fall of about 250 feet—much greater than that of the main river; they are all found on the north side. These branches, Montello, Mecan, and White rivers, start as clear, steady springs, running from the sand ridges of the drift covering that portion of the basin. They are each about 20 miles long, and would be unimportant except for the fact that their fall, combined with their steadiness of flow, makes them of considerable value.

Montello River joins the upper Fox at Montello. A dam at this point has a head of 11 feet, furnishing power for a flouring mill and a woolen mill. This head could be easily increased to 16 feet.

ollowing table shows the principal developed powers on the tributaries of the ox.

Developed water powers on tributaries of upper Fox River.

Location and stream.	Owner and use.	Head.	H. P.
Little River	C. F. Stollyman, flour and feed	10	33
², Duck Creek	C. E. Pierce, flour and feed	11	70
ter, Grand River	G. Pfeiffer, flour	12	45
ad, De Nevue Creek	D. I. Williams, flour and feed	30	30
ı, Grand River	P. Wieski, flour and feed	11	30
Neenah Creek	H. Larmer, flour and feed	9	70
	H. E. McNutt, flour and feed	14	190
er, Pine Creek	Skinner & Johnson, flour and feed	14	60
, Pine Creek	W. H. Paulsen, flour and feed	9	70
ı, ditch from Mecan River	Teske & Zierka, flour, feed, and electric light	19	180
ilver Creek	Nohr Milling Co., flour and feed	12	120
, Pine Creek	B. W. Heald, flour and feed	10	54
der, Waumander Creek	A. G. Ochsner, flour	15	27
a, Mecan River	William Henke, flour and feed	8	36
l, Montello River	Cochran & Nettinger, flour and feed	10	85

LOWER FOX.

GEOLOGY AND TOPOGRAPHY.

of Wolf River Valley is the more prominent though similar valley of Green Bay and innebago. In pre-Glacial time it must have been much smaller in size, having been ed to its present great size by the glacier. Lake Winnebago alone covers about 200 niles, while the area of the connecting valley below (lower Fox River) is 400 square

estern slope of both valleys is gradual, but the eastern slope is precipitous, being cut he soft Cincinnati shales overlain by the hard "Niagara" limestone. The bed is l "Galena" limestone of the "Trenton" series. The eastern side of the lower Fox rainage basin rises abruptly 100 to 200 feet above the water in Green Bay, and es as a line of cliffs along the eastern shore of the present Lake Winnebago, and outhward, though largely covered with drift in the southern part of the State. The action sent down an immense ice sheet, cutting out the valley of Lake Michigan, branch tongue gouged out Green Bay Valley to its present size. On the peninsula Green Bay and Lake Michigan was formed the prominent Kettle Range, a medial

loor of Green Bay Valley has a rapid rise, Lake Winnebago being 166 feet above lay. The portion of the old valley now occupied by the upper Fox was largely th drift, and it seems probable that to the action of the glacier in cutting down rvening "Lower Magnesian" rampart and in partially filling the upper valley of Fox ı due the change in the flow of upper Fox and Wolf rivers through the newly l Green Bay Valley to the lake. It is also likely that the change in flow is partly ı depression toward the north, which occurred during or after the recession of the as suggested by Major Warren. This depression caused an advance of Lake Michi- ich rearranged the drift and deposited the red clays. By means of the latter this shore of the lake can now be traced northward beyond Shawano, on Wolf River, d up Fox River above Berlin, and southward to a few miles north of Fond du Lac. innebago is a comparatively modern reservoir, formed in the valley by the deposi- glacial drift.

PROFILE.

The table below gives in detail the profile of the river to-day, after the extensive navigation improvements by the United States Government:

Profile of Fox River from Lake Winnebago (Menasha) to Green Bay.[a]

Station.	Distance.		Elevation above sea level.	Descent between points.	
	From Menasha.	Between points.		Total.	Per mile.
	Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
Menasha dam, crest	0.0	.....	746.1	.....	.....
Appleton upper lock, crest	5.1	5.1	736.5	9.6	1.9
Appleton locks, foot	6.3	1.2	699.7	36.8	30.6
Cedars lock, crest	9.6	3.3	699.7	.0	.0
Littlechute locks:					
Crest	10.6	1.0	690.0	9.7	9.7
Foot	11.6	1.0	653.8	36.2	36.2
Grand Kaukauna locks:					
Crest	13.3	1.7	653.8	.0	.0
Foot	14.2	.9	603.3	50.5	56.1
Rapide Croche lock:					
Crest	17.9	3.7	603.3	.0	.0
Foot	17.9	.25	593.9	9.4	37.6
Little Kaukauna lock:					
Crest	23.9	6.0	593.9	.0	.0
Foot	23.9	.2	587.7	6.2	31.0
Depere lock:					
Crest	29.8	5.9	587.7	.0	.0
Foot	29.8	.0	580.0	7.7	.....
Green Bay	35.2	5.4	580.0	.0	.....

[a] From United States engineer's profile of the river.

These improvements have changed the river into long stretches of slack water, with perhaps short rapids at the foot of a dam, except at Grand Kaukauna and Grand Chute, the site of the city of Appleton, where the rapids are passed by canals, while the river flows over its original steep bed.

RAINFALL AND RUN-OFF.

The United States engineers have maintained a gaging station at Rapide Croche dam ever since March, 1896. The assistant engineer in charge, L. M. Mann, states that the crest of the dam at this point is well suited for a weir. Care is taken to read the gage three times daily, the mean reading being used to calculate the daily discharge.

According to these records the mean low-water discharge for the past eight years was 1,409 second-feet and the average discharge 3,007 second-feet; 2,660 second-feet may be regarded as the ordinary flow of the river. Because of the steadying effect of Lake Winnebago and the lakes above, formed by the expansion of upper Fox and Wolf rivers, the discharge of the river is remarkably uniform. At Appleton the ordinary variation from low to high water is scarcely more than 2 or 3 feet throughout the year.

The following table gives the maximum, the minimum, and the average flow for each month for nearly nine years, ending December, 1904, as measured at Rapide Croche dam, and also the rainfall and run-off for the same period:

Estimated monthly discharge of lower Fox River at Rapide Croche dam.

[Drainage area, 6,200 square miles.]

Month.	Discharge in second-feet.			Run-off.		Rainfall.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Inches.	Per cent of rainfall.
1895.							
r	4,972	2,262	3,931	0.634	0.731	.....	.....
ry	5,201	2,545	4,320	.697	.726	.....	.....
.....	5,796	2,062	3,947	.637	.734	.....	.....
.....	12,706	3,076	8,510	1.37	1.53	.....	.....
.....	6,386	4,233	5,610	.905	1.04	.....	.....
.....	15,416	6,628	12,760	2.06	2.30	.....	.....
.....	11,982	3,451	7,612	1.23	1.42	.....	.....
.....	5,173	3,047	4,424	.714	.823	.....	.....
ber	5,072	2,242	3,988	.643	.717	.....	.....
r	4,185	2,071	3,417	.551	.635	.....	.....
1896.							
.....	1,739	697	1,284	.207	.239	1.14	21.0
.....	1,765	406	940	.152	.170	4.39	3.87
.....	4,246	1,563	3,140	.506	.583	5.23	11.1
.....	4,605	2,173	3,726	.601	.670	2.75	24.4
.....	3,863	880	2,787	.450	.519	3.09	16.8
.....	2,607	123	1,470	.237	.273	3.09	8.83
ber	390	9	146	.024	.027	3.23	.84
r	1,888	145	1,065	.172	.198	2.55	7.76
ber	2,882	985	2,007	.324	.362	3.06	11.8
ber	3,558	838	2,367	.382	.440	1.04	42.3
he year	.....	.....	.....	.....	.....	29.57	.....
1897.							
r	3,795	1,512	2,762	.445	.513	1.37	37.5
ry	3,522	1,297	2,765	.446	.464	1.17	39.6
.....	5,344	1,160	2,711	.437	.504	2.19	23.1
.....	8,728	3,296	6,132	.989	1.10	2.00	55.0
.....	5,344	2,519	4,016	.648	.747	1.74	42.9
.....	4,749	2,032	3,246	.524	.585	5.06	11.6
.....	4,071	1,297	3,200	.516	.595	3.51	16.9
.....	3,230	116	1,881	.303	.349	2.00	17.4
ber	1,588	272	833	.134	.150	2.53	5.9
r	2,608	299	1,424	.230	.265	2.15	12.3
ber	2,664	861	1,862	.300	.335	1.50	22.3
ber	3,770	806	2,314	.373	.430	.86	50.0
he year	8,728	116	2,762	.445	6.04	26.08	23.2
1898.							
r	3,158	1,425	2,559	.413	.476	.71	67.1
ry	3,196	1,494	2,359	.380	.397	1.21	32.8
.....	3,872	1,782	2,968	.479	.552	2.18	25.3
.....	5,692	2,568	4,079	.658	.734	2.02	36.4
.....	6,852	2,204	4,743	.765	.882	2.75	32.1
.....	4,969	1,604	3,216	.519	.579	3.84	15.1
.....	2,553	438	1,571	.253	.292	3.09	9.45
.....	2,805	866	1,817	.293	.338	3.00	11.3
ber	1,795	442	1,088	.175	.195	2.36	8.25
r	2,368	383	1,201	.194	.224	3.15	7.10

Estimated monthly discharge of lower Fox River at Rapide Croche dam—Continued.

Month.	Discharge in second-feet.			Run-off.		Rainfall.	Per cent of rainfall.
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Inches.	
1898.							
November	2,725	1,234	2,213	0.357	0.398	1.49	26.7
December	2,805	994	2,175	.351	.405	.35	116.0
The year	6,852	383	2,499	.403	5.47	26.15	20.9
1899.							
January	2,417	771	1,905	.307	.354	1.12	31.6
February	2,810	1,014	2,075	.335	.349	.90	38.8
March	3,435	995	2,252	.363	.418	2.31	18.2
April	5,707	1,447	3,657	.590	.658	3.00	21.9
May	8,767	3,787	6,209	1.00	1.15	3.08	37.3
June	8,571	4,018	6,298	1.02	1.14	5.40	21.2
July	5,171	1,741	3,786	.611	.704	3.29	21.4
August	3,505	791	1,836	.296	.341	2.73	12.5
September	1,437	707	988	.159	.177	2.68	6.60
October	2,079	398	1,144	.185	.213	3.02	7.05
November	2,648	613	2,119	.342	.382	.74	51.6
December	2,572	105	2,042	.329	.379	1.47	25.4
The year	8,767	105	2,859	.461	6.26	29.74	21.1
1900.							
January	2,684	841	2,174	.351	.405	.74	54.7
February	3,024	1,044	2,247	.362	.377	1.56	24.2
March	3,677	1,110	2,556	.412	.475	1.09	43.6
April	4,355	1,107	3,414	.551	.615	2.82	21.8
May	4,054	1,383	2,976	.480	.553	1.61	34.5
June	2,208	258	873	.141	.157	2.68	5.86
July	2,413	131	958	.154	.178	6.45	2.76
August	2,646	1,057	1,831	.295	.340	4.30	7.91
September	3,518	1,107	2,021	.326	.364	6.17	5.90
October	8,036	1,734	5,230	.844	.973	7.08	13.7
November	9,597	4,948	8,062	1.30	1.45	1.57	92.4
December	8,222	1,668	4,353	.702	.809	.69	117.0
The year	9,597	131	3,058	.493	6.70	36.76	18.2
1901.							
January	4,349	1,939	3,526	.569	.656	.90	72.9
February	4,634	1,825	3,773	.609	.634	.46	138.0
March	6,431	1,742	3,839	.619	.714	3.04	23.5
April	12,033	2,469	8,960	1.45	1.62	.79	205.0
May	6,905	3,453	4,994	.805	.928	2.72	34.1
June	5,087	1,741	3,723	.600	.669	4.62	14.5
July	4,557	2,045	3,501	.565	.651	6.41	10.2
August	3,846	1,130	2,176	.351	.405	2.38	17.2
September	1,687	675	1,221	.197	.220	3.96	5.56
October	3,873	9,910	2,551	.411	.474	2.93	16.2
November	3,873	1,640	3,256	.525	.586	1.25	46.9
December	3,672	1,464	2,768	.446	.514	.81	63.5
The year	12,033	675	3,691	.596	8.07	30.27	26.7

Estimated monthly discharge of lower Fox River at Rapide Croche dam—Continued.

Month.	Discharge in second-feet.			Run-off.		Rainfall.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Inches.	Per cent of rainfall.
1902.							
January	3,136	765	2,263	0.365	0.421	0.69	61.1
February	3,480	696	2,142	.345	.359	1.53	23.5
March	4,019	1,135	2,892	.466	.537	1.50	35.8
April	3,252	947	2,335	.377	.421	2.42	17.4
May	12,317	1,471	4,935	.796	.918	4.02	22.8
June	11,868	3,491	6,930	1.12	1.25	3.89	22.1
July	5,703	1,647	4,304	.694	.800	5.47	14.6
August	4,086	1,311	2,896	.467	.538	1.40	38.4
September	1,865	515	1,266	.204	.228	2.81	8.11
October	3,024	435	1,818	.293	.338	1.94	17.4
November	3,184	756	2,394	.386	.431	2.90	14.9
December	3,100	892	2,274	.367	.423	1.93	21.9
The year	12,317	435	3,037	.490	6.66	30.50	21.8
1903.							
January	3,756	1,206	2,760	.445	.513	.47	109.5
February	3,652	1,675	2,949	.476	.496	.80	62.0
March	8,437	1,780	3,827	.617	.711	3.12	22.8
April	9,297	3,886	6,500	1.05	1.17	3.14	37.3
May	7,378	3,043	5,532	.892	1.03	5.87	17.5
June	6,791	2,656	5,061	.816	.910	2.14	42.5
July	5,571	1,856	4,124	.665	.767	5.47	14.0
August	4,449	1,438	3,446	.556	.641	6.23	10.3
September	5,519	1,829	4,321	.697	.778	5.91	13.2
October	5,826	2,590	4,686	.756	.872	2.75	31.7
November	5,077	1,733	3,686	.595	.664	1.14	58.3
December	3,702	1,319	2,885	.465	.536	.71	75.5
The year	9,297	1,206	4,148	.669	9.09	37.75	24.1
1904.							
January	3,869	1,185	3,074	.496	.571	.38	150.0
February	4,134	1,565	3,128	.505	.545	1.45	37.6
March	7,425	1,724	3,398	.548	.632	1.80	35.1
April	9,637	1,612	6,669	1.08	1.20	1.86	64.5
May	11,682	4,456	8,707	1.40	1.61	5.93	27.1
June	9,793	2,336	6,682	1.08	1.20	3.99	30.1
July	4,111	1,416	3,105	.501	.578	3.98	14.5
August	4,043	1,551	2,985	.481	.554	3.01	18.4
September	2,631	988	1,854	.299	.334	5.75	5.81
October	6,434	1,324	3,457	.558	.643	4.73	13.6
November	6,935	1,667	4,056	.654	.730	.30	243.5
December	4,594	1,812	3,618	.584	.673	2.13	31.6
The year	11,682	988	4,228	.682	9.270	35.31	26.2

Mean daily discharge, in second-feet, of lower Fox River at Rapide Croche dam.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1895.												
1	3,012	4,672	4,697	4,798	4,373	6,628	11,982	4,884	4,698	2,071	.....	.....
2	2,262	4,328	4,438	3,185	5,852	7,339	10,639	4,963	5,072	2,132	.....	.....
3	3,350	4,766	4,285	3,076	5,880	6,935	10,433	4,964	3,387	3,546	.....	.....
4	3,781	5,164	4,260	5,064	5,910	7,225	10,585	4,936	3,048	3,584	.....	.....
5	4,447	3,765	2,846	5,595	5,949	8,277	10,664	5,173	3,788	3,366	.....	.....
6	4,269	2,689	2,611	5,998	6,135	15,416	10,639	3,411	4,102	3,554	.....	.....
7	4,285	4,785	3,982	5,804	4,493	14,244	9,415	3,385	4,487	3,932	.....	.....
8	3,024	4,973	3,998	7,052	4,233	14,178	9,206	4,382	4,395	3,057	.....	.....
9	2,967	5,063	4,021	8,803	5,546	15,132	7,865	4,847	4,430	2,504	.....	.....
10	4,244	5,009	4,419	9,422	6,386	14,286	7,416	4,898	3,969	3,899	.....	.....
11	4,422	5,173	4,214	11,435	6,155	14,122	8,803	4,242	3,106	3,971	.....	.....
12	4,594	4,061	2,704	12,354	6,037	14,060	9,124	4,847	4,372	4,022	.....	.....
13	4,559	2,892	2,264	12,706	6,066	14,559	9,066	3,577	4,144	3,884	.....	.....
14	4,102	4,830	2,062	12,187	4,642	14,585	8,769	3,383	4,327	3,764	.....	.....
15	3,112	5,201	3,892	12,033	4,399	14,219	8,521	4,849	4,447	2,774	.....	.....
16	2,497	4,785	3,685	11,063	6,179	14,365	7,165	4,937	4,243	2,227	.....	.....
17	3,916	4,723	3,876	11,110	6,165	14,588	6,699	4,937	2,856	3,955	.....	.....
18	4,244	4,637	4,313	11,637	6,274	13,981	8,860	5,027	2,826	4,052	.....	.....
19	4,602	3,369	2,529	12,277	5,891	14,277	7,873	4,785	4,236	4,086	.....	.....
20	4,654	2,545	2,098	11,879	6,115	14,279	6,597	3,047	4,405	3,939	.....	.....
21	4,619	4,839	4,228	10,336	4,803	14,191	6,577	3,526	4,447	3,956	.....	.....
22	3,027	4,910	4,490	10,639	4,386	13,419	5,804	4,794	4,294	2,088	.....	.....
23	2,963	4,847	5,796	9,406	5,804	13,674	4,583	4,892	4,337	2,173	.....	.....
24	4,742	4,777	5,757	9,032	6,047	13,513	3,451	5,036	2,974	3,917	.....	.....
25	4,829	4,356	5,626	9,208	5,880	12,524	5,797	5,019	2,242	4,021	.....	.....
26	4,576	3,055	4,508	7,661	5,880	11,892	6,179	4,804	4,030	4,069	.....	.....
27	4,972	2,575	3,546	5,862	5,841	14,021	5,498	3,593	4,421	4,081	.....	.....
28	4,653	4,186	4,353	6,164	4,566	12,265	5,545	3,518	4,162	4,160	.....	.....
29	3,413	.....	4,268	6,144	5,129	12,509	5,192	4,145	4,285	2,710	.....	.....
30	3,137	.....	4,395	3,362	6,597	12,251	3,562	4,086	4,127	2,263	.....	.....
31	4,576	.....	4,185	.....	6,312	.....	3,480	4,26[illegible]	.....	4,185	.....	.....
Total	121,850	120,975	122,346	255,292	173,925	382,954	235,989	137,156	119,657	105,942	.....	.....
1896.												
1	.....	.....	888	1,272	2,406	2,789	3,694	912	259	145	985	2,821
2	.....	.....	697	1,027	2,088	4,246	3,728	1,048	298	608	1,048	3,135
3	.....	.....	1,386	922	1,563	4,246	3,761	1,512	179	838	1,512	3,230
4	.....	.....	1,226	760	1,639	4,141	2,032	2,314	78	608	1,537	3,558
5	.....	.....	1,395	1,048	3,493	4,282	880	2,461	36	683	1,872	3,135
6	.....	.....	1,338	780	3,166	3,967	1,820	2,578	36	1,440	1,872	1,952
7	.....	.....	1,430	761	3,312	3,897	3,592	2,607	179	880	1,792	2,372
8	.....	.....	1,113	922	2,993	3,135	3,394	2,490	328	1,070	1,563	2,821
9	.....	.....	919	859	3,230	4,461	3,863	1,250	390	880	1,093	2,789
10	.....	.....	1,271	964	2,032	4,282	3,728	1,392	122	1,093	2,201	2,913
11	.....	.....	1,479	859	1,575	4,605	3,761	1,818	192	608	2,229	2,913
12	.....	.....	1,407	406	3,361	4,389	2,201	1,818	136	779	2,638	2,729
13	.....	.....	1,407	644	3,427	4,106	1,952	1,765	48	1,093	2,729	1,647
14	.....	.....	1,271	859	3,476	3,296	3,592	1,723	48	964	2,729	1,672
15	.....	.....	981	922	3,558	2,913	3,525	2,006	205	922	1,115	2,519
16	.....	.....	837	985	3,396	4,037	3,525	985	145	1,093	1,160	2,460
17	.....	.....	1,437	1,048	2,686	3,796	3,694	1,352	192	1,138	2,460	2,607
18	.....	.....	1,248	985	2,460	3,897	3,296	2,006	134	608	2,729	2,578
19	.....	.....	1,486	644	3,591	3,897	1,872	2,032	78	722	2,668	2,578
20	.....	.....	1,366	608	3,897	3,897	1,672	2,061	195	1,362	2,729	1,563

Mean daily discharge, in second-feet, of lower Fox River at Rapide Croche dam—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1896.												
21	.....	.....	1,414	943	3,897	2,431	2,913	2,006	17	1,647	2,882	1,613
22	.....	.....	1,024	943	3,897	2,461	2,607	1,899	145	1,440	1,639	2,519
23	.....	.....	1,024	901	4,071	3,967	2,314	2,454	134	1,563	1,440	2,460
24	.....	.....	1,739	985	2,729	4,211	2,607	838	36	1,613	2,608	2,431
25	.....	.....	1,461	1,273	2,387	3,932	2,607	327	112	543	2,789	838
26	.....	.....	1,224	556	3,932	4,141	1,563	123	122	556	2,821	1,160
27	.....	.....	1,179	780	4,246	3,897	1,563	259	27	1,440	2,669	838
28	.....	.....	1,605	1,027	4,071	2,608	2,913	375	9	1,272	1,818	1,792
29	.....	.....	1,337	1,765	4,161	2,173	2,669	406	374	1,845	1,205	2,913
30	.....	.....	1,522	1,765	4,071	3,693	2,490	453	134	1,888	1,672	2,607
31	.....	.....	1,707	.....	2,519	.....	2,578	312	.....	1,672	.....	2,229
Total	.....	.....	39,818	28,213	97,330	111,793	86,406	45,582	4,388	33,013	60,204	73,392
1897.												
1	2,201	1,563	1,472	3.728	5,344	3,263	3,761	2,314	468	1,160	1,160	1,820
2	2,173	3,040	3,263	4,037	4,071	3,659	3,863	1,765	621	1,070	1,983	1,832
3	1,512	3,361	3,263	4,966	4,002	3,727	4,037	3,103	343	702	2,209	2,128
4	2,088	3,103	3,135	3,296	4,886	3,727	2,490	3,103	328	556	2,615	2,226
5	2,789	3,072	3,395	4,037	5,079	3,761	1,297	3,230	328	1,138	2,642	1,638
6	3,104	3,263	2,608	5,624	4,713	2,201	2,173	3,072	390	1,115	2,664	1,196
7	3,394	1,440	1,183	6,329	4,605	2,402	4,002	3,040	272	1,160	1,973	2,401
8	3,008	1,563	1,393	6,329	4,354	3,361	4,071	1,926	539	1,183	1,390	2,474
9	2,759	3,008	2,431	6,533	3,198	3,230	3,932	1,416	702	985	1,861	2,497
10	2,607	3,361	2,490	6,533	2,759	3,329	3,932	2,760	556	741	1,964	2,748
11	2,286	3,040	2,461	5,231	4,354	3,459	2,402	2,608	664	556	1,912	2,568
12	3,072	3,198	2,578	4,789	4,497	3,659	2,402	2,490	390	1,345	1,964	1,905
13	3,198	3,198	2,461	6,614	4,461	2,229	3,459	2,490	390	1,512	2,183	1,102
14	3,072	2,189	1,512	6,410	4,141	2,229	3,558	2,608	819	1,512	1,481	2,512
15	3,040	1,297	1,160	6,533	4,425	3,394	3,694	1,440	1,416	1,897	1,092	3,409
16	2,788	3,103	2,490	6,329	3,329	4,749	3,897	1,345	1,588	1,952	1,833	3,439
17	1,644	3,072	2,314	6,779	2,913	4,037	3,694	3,431	1,440	1,048	1,912	3,770
18	1,872	3,230	2,619	7,072	4,106	3,727	2,229	2,638	1,205	722	1,964	1,880
19	3,230	3,198	3,460	5,419	4,282	3,727	2,006	2,431	761	1,897	2,432	2,213
20	3,795	3,361	5,344	7,114	4,425	2,286	3,394	1,765	702	2,061	2,412	1,559
21	3,459	1,639	2,821	7,582	4,318	2,314	3,558	1,093	943	1,897	1,387	2,424
22	3,198	1,723	2,461	7,326	4,461	3,525	3,761	1,048	1,205	1,897	861	2,665
23	3,394	3,135	3,694	8,728	3,072	3,525	3,694	1,352	1,393	299	2,045	2,642
24	2,759	3,522	3,626	8,549	2,759	3,592	3,525	1,273	1,369	1,115	1,207	2,732
25	1,899	3,378	3,328	6,946	4,141	3,263	1,926	1,273	1,160	1,239	2,476	1,878
26	2,945	3,458	3,394	6,329	4,246	3,528	2,117	901	644	2,117	2,107	806
27	2,945	3,135	3,135	7,539	4,246	2,343	3,008	1,160	838	2,490	2,148	1,657
28	3,103	1,765	1,512	6,329	4,071	2,032	3,198	343	1,138	2,373	1,281	2,900
29	3,361	.....	1,962	5,459	4,071	3,932	3,394	374	1,183	2,608	1,097	2,808
30	3,103	.....	3,394	5,459	2,638	3,727	3,394	116	1,183	2,286	1,602	2,923
31	1,818	.....	3,694	.....	2,519	.....	3,329	403	.....	1,512	.....	2,969
Total	85,616	77,415	84,053	183,948	124,486	97,397	99,197	58,311	24,978	44,145	55,857	71,721
1898.												
1	3,063	2,793	2,676	4,056	3,776	4,969	2,553	876	1,652	602	2,609	2,805
2	2,099	2,762	2,698	4,176	3,799	4,522	2,496	1,546	1,795	554	2,351	2,766
3	1,425	2,931	2,753	2,846	5,508	4,579	1,771	1,649	1,639	517	2,237	2,714
4	2,535	3,196	2,908	2,568	5,016	4,397	438	1,670	1,317	857	2,134	1,789
5	3,000	3,062	2,752	3,890	6,668	3,578	1,868	1,585	726	595	2,187	1,647
6	3,039	2,038	1,699	4,072	6,852	2,388	1,865	1,667	1,454	771	1,457	2,479

Mean daily discharge, in second-feet, of lower Fox River at Rapide Croche dam—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1898.												
7	2,946	1,766	1,782	4,159	6,098	4,018	1,769	973	1,532	801	1,234	2,609
8	2,977	2,504	3,064	4,115	4,921	4,468	1,639	1,074	1,629	1,024	2,017	2,699
9	1,873	2,665	3,669	4,150	4,333	4,276	1,466	1,653	1,735	383	2,475	2,572
10	1,396	2,583	3,761	2,925	5,889	4,175	1,096	1,685	1,714	638	2,485	1,379
11	2,953	2,701	3,394	2,837	5,904	4,364	1,042	1,695	1,133	1,056	2,497	2,153
12	2,969	2,679	3,192	4,291	5,683	3,215	1,535	1,660	750	1,092	2,542	1,539
13	2,901	1,723	1,868	4,273	5,487	2,524	1,757	1,835	1,288	1,246	1,543	2,345
14	2,946	1,578	1,902	4,054	5,432	3,690	1,798	1,213	1,115	1,155	1,451	2,637
15	3,079	2,331	3,224	4,189	4,018	3,703	1,842	1,226	1,186	1,156	2,438	2,791
16	1,864	2,549	3,288	4,301	3,457	3,723	1,792	1,765	1,080	745	2,453	2,715
17	1,569	2,490	3,111	2,924	4,551	3,167	1,074	2,273	1,177	755	2,552	2,215
18	2,908	2,468	3,135	3,025	5,088	3,690	1,245	2,460	778	1,300	2,563	1,343
19	2,799	2,497	3,435	4,372	4,758	2,343	1,699	2,805	442	1,178	2,482	1,462
20	3,078	1,528	1,938	4,650	4,647	2,076	1,639	2,752	760	1,304	1,747	2,453
21	2,859	1,587	2,235	4,776	4,739	2,453	1,616	2,024	818	1,892	1,281	2,409
22	2,915	2,403	3,280	5,692	3,577	2,623	1,664	866	959	1,865	2,704	2,398
23	1,925	2,409	3,200	4,894	3,157	2,603	1,685	2,571	906	1,136	2,549	2,241
24	1,741	2,505	3,122	3,176	4,338	2,624	1,088	2,579	933	760	2,499	2,303
25	2,962	2,403	3,643	3,462	4,594	2,488	989	2,482	676	2,043	2,725	994
26	2,985	2,505	3,361	4,656	4,471	1,623	1,557	2,468	491	1,815	2,572	1,017
27	3,077	1,494	2,565	5,089	4,739	1,604	1,641	2,572	681	1,845	1,486	1,544
28	3,158	1,914	3,035	5,136	4,612	1,863	1,618	1,942	693	2,064	1,402	2,412
29	2,904	.....	3,872	4,767	3,857	2,230	1,687	1,195	877	2,233	2,606	2,446
30	1,851	.....	3,728	4,839	2,204	2,567	1,661	1,848	693	1,489	2,519	2,315
31	1,461	.....	3,736	.....	4,872	.....	1,117	1,717	.....	2,368	.....	2,244
Total	79,317	66,064	92,026	122,360	147,045	96,483	48,707	56,326	32,629	37,239	66,397	67,435
1899.												
1	1,533	2,111	1,931	3,279	3,787	5,209	5,042	3,345	1,292	831	2,104	2,205
2	1,488	2,174	2,113	1,837	5,020	5,238	4,031	3,505	1,437	764	2,648	2,455
3	2,366	2,275	2,134	1,447	5,121	5,432	3,133	3,121	842	1,560	2,542	1,667
4	2,417	2,261	2,113	3,756	5,417	4,733	3,678	2,396	1,003	1,037	2,446	952
5	2,187	1,453	1,352	4,249	5,395	4,018	3,361	2,418	1,411	996	1,742	2,549
6	2,393	2,458	1,279	4,641	5,500	5,518	4,923	1,745	1,121	1,193	1,261	2,411
7	2,173	2,175	1,976	4,839	4,446	5,633	5,171	956	991	1,100	2,579	2,475
8	1,466	1,303	1,932	4,425	4,145	5,565	4,726	2,043	953	928	2,622	2,572
9	1,465	2,681	2,027	2,823	5,924	5,062	3,942	2,585	996	774	2,523	2,530
10	2,316	2,572	2,062	2,249	6,192	5,369	3,019	2,394	792	904	2,635	1,775
11	2,329	2,810	2,034	3,741	6,618	4,406	4,592	2,343	578	922	2,619	1,020
12	2,316	2,047	2,355	3,821	7,601	4,334	4,715	2,357	945	1,056	1,890	2,366
13	2,106	1,711	1,336	3,812	8,050	5,878	4,882	1,547	825	1,144	1,143	2,498
14	2,406	2,588	1,913	3,976	7,301	7,091	4,852	1,250	891	982	2,187	2,352
15	1,514	2,646	2,289	3,721	7,763	7,080	4,974	1,852	889	779	2,381	2,395
16	1,604	2,534	2,692	2,199	8,562	7,681	3,773	1,812	831	398	2,351	2,339
17	2,254	2,619	2,612	2,004	8,767	7,408	3,021	1,829	831	969	2,352	1,780
18	2,379	2,453	2,553	3,461	7,838	6,702	4,516	1,946	1,001	1,039	2,261	1,259
19	2,352	1,243	1,553	3,946	8,421	6,853	4,511	1,973	1,166	1,179	1,774	2,576
20	2,347	1,291	995	3,778	8,431	8,123	4,186	1,026	996	1,304	613	2,381
21	2,330	1,902	2,731	3,955	7,046	8,095	3,881	1,163	1,039	1,327	2,301	2,388
22	1,409	2,117	3,001	4,154	6,272	8,571	3,701	1,578	991	885	2,205	2,417
23	1,506	2,152	2,756	2,798	5,263	8,515	2,459	1,609	855	685	2,237	2,497
24	1,729	1,995	2,832	2,813	5,333	8,277	1,741	1,772	707	1,480	2,209	1,752
25	1,562	2,104	2,829	4,336	5,451	7,338	3,193	1,317	719	1,551	2,352	105
26	1,690	1,395	1,910	4,524	5,263	6,594	3,336	1,339	922	1,404	1,873	958

Mean daily discharge, in second-feet, of lower Fox River at Rapide Croche dam—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1899.												
27	1,981	1,014	1,243	4,565	5,525	7,372	3,364	944	1,138	1,829	905	2,123
28	771	2,007	3,192	5,707	5,898	6,029	3,395	791	1,099	2,029	2,329	2,185
29	1,506	.....	3,297	4,913	5,160	5,797	3,232	1,307	1,206	1,493	2,159	2,417
30	1,346	.....	3,325	3,947	5,466	5,007	2,051	1,351	1,166	769	2,330	2,241
31	1,803	.....	3,435	.....	5,513	.....	1,982	1,299	.....	2,079	.....	1,659
Total	59,044	58,091	69,802	109,716	192,489	188,928	117,383	56,913	29,653	35,450	63,573	63,299
1900.												
1	841	2,395	2,432	2,454	3,636	1,482	276	2,646	1,976	1,734	9,535	6,608
2	2,352	2,366	2,468	1,107	3,882	1,574	511	2,106	1,640	4,007	9,397	4,372
3	2,391	2,446	2,490	3,554	4,028	1,375	319	1,946	1,421	5,185	9,597	3,512
4	2,406	1,641	1,707	3,846	4,010	1,102	131	1,966	1,962	5,479	8,225	5,674
5	2,479	1,044	1,110	3,967	4,054	1,929	820	1,638	2,141	4,846	7,650	5,943
6	2,568	2,366	1,342	4,063	2,779	2,208	352	1,287	1,894	4,758	8,989	5,807
7	1,576	2,381	2,576	3,791	1,674	2,085	345	1,956	2,050	3,657	9,039	5,683
8	1,213	3,024	2,639	2,903	2,461	1,467	294	1,912	2,113	2,848	8,418	5,439
9	2,406	2,420	2,614	1,751	2,283	1,302	365	2,075	1,333	4,827	8,658	8,222
10	2,669	2,398	2,636	3,510	2,275	989	473	1,973	1,143	5,165	9,260	3,586
11	2,684	1,675	1,921	3,770	2,240	1,013	353	2,043	1,973	5,117	7,830	5,245
12	2,646	1,071	1,352	4,067	2,285	1,217	333	1,498	2,071	4,813	7,567	5,052
13	2,677	2,316	2,666	4,006	1,784	1,189	394	1,057	2,187	4,668	8,775	5,075
14	1,736	2,654	2,973	4,080	1,753	756	382	1,825	2,075	3,559	8,456	5,301
15	1,236	2,707	3,036	2,560	3,741	353	538	1,905	2,184	3,028	8,076	4,099
16	2,527	2,729	2,961	2,237	3,989	497	979	1,889	1,163	4,461	6,611	2,725
17	2,424	2,662	2,935	3,942	3,799	394	1,176	2,039	1,167	4,885	6,909	2,240
18	2,639	1,895	2,069	4,355	3,885	437	1,067	2,002	1,949	5,285	5,654	4,118
19	2,534	1,314	1,354	4,089	3,791	573	907	1,434	1,899	5,254	4,948	4,292
20	2,657	2,861	2,710	4,137	2,665	523	1,192	1,120	2,062	5,703	7,536	4,314
21	1,719	2,840	2,832	4,072	2,105	569	1,152	2,120	2,020	4,599	7,875	4,378
22	1,043	2,606	2,904	2,932	3,729	585	799	2,007	2,169	4,225	8,249	4,457
23	2,632	2,687	2,954	1,977	3,937	264	1,170	1,875	1,433	6,510	8,189	4,035
24	2,549	2,646	3,296	3,856	3,872	262	1,846	1,966	1,107	6,270	8,792	1,668
25	2,461	1,434	2,259	4,089	3,889	396	2,047	1,924	2,329	7,427	7,100	3,224
26	2,579	1,296	1,300	4,106	3,694	258	1,982	1,440	2,891	7,572	6,917	2,621
27	2,420	2,411	3,159	4,063	2,539	360	1,970	1,115	2,810	7,624	8,415	4,068
28	1,508	2,624	3,644	4,225	1,383	298	1,905	1,912	3,391	6,393	8,632	4,147
29	1,219	.....	3,677	2,862	2,103	386	1,536	1,928	3,518	6,336	8,328	4,111
30	2,166	.....	3,560	2,064	2,149	341	1,672	2,127	2,561	7,855	8,239	3,191
31	2,439	.....	3,652	.....	1,859	.....	2,413	2,023	.....	8,036	.....	1,728
Total	67,396	62,909	79,228	102,435	92,273	26,184	29,708	56,754	60,632	162,126	241,866	134,935
1901.												
1	3,822	3,475	4,362	2,469	6,328	4,803	2,045	3,834	1,197	1,161	3,664	2,586
2	4,000	3,734	4,262	4,664	6,905	3,802	3,496	3,846	1,161	1,782	3,804	1,685
3	4,215	2,659	2,741	5,086	5,990	3,473	3,740	3,787	1,636	1,863	2,674	2,653
4	4,202	1,825	2,109	5,209	6,032	4,913	2,618	2,648	1,682	1,748	1,789	3,520
5	4,253	3,723	4,073	5,385	4,769	5,087	3,194	1,713	1,687	1,713	3,699	3,497
6	3,016	4,096	4,481	6,081	3,799	4,905	4,097	2,553	1,682	1,228	3,728	3,459
7	2,043	4,352	4,262	6,777	5,707	4,647	2,945	2,605	1,649	991	3,711	3,648
8	3,939	4,515	4,262	7,075	5,536	4,846	2,722	2,321	1,105	2,067	3,728	2,329
9	4,279	4,541	4,210	10,675	5,498	2,834	4,185	2,406	893	2,145	3,584	1,598
10	4,349	2,796	2,908	10,986	5,574	2,654	4,557	2,336	1,449	2,265	2,585	3,257
11	4,159	2,045	1,793	11,579	5,428	3,873	4,080	1,503	984	2,468	1,654	3,585
12	4,009	4,164	2,206	12,033	4,183	3,916	4,154	1,607	1,199	2,314	3,447	3,669

Mean daily discharge, in second-feet, of lower Fox River at Rapide Croche dam—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901.												
13	3,046	4,181	4,000	11,573	3,754	4,443	4,041	2,579	1,051	1,740	3,766	3,672
14	2,235	4,434	4,121	11,088	5,012	4,273	3,131	2,512	1,194	1,260	3,766	3,139
15	3,914	4,262	4,059	10,728	5,564	3,911	2,809	2,497	706	3,633	3,771	2,524
16	3,929	4,292	4,169	11,869	5,428	2,586	3,996	2,642	1,146	3,357	3,856	1,555
17	2,480	3,068	2,818	11,935	5,371	1,741	4,089	2,575	1,009	3,252	2,697	2,894
18	3,542	2,227	1,742	11,614	5,011	3,475	4,002	1,617	1,039	3,366	1,661	3,349
19	3,981	4,309	3,967	11,467	4,099	4,087	3,898	1,404	1,004	3,136	3,644	3,316
20	2,965	4,470	4,030	11,334	3,715	4,148	4,067	1,737	1,090	2,099	3,873	2,939
21	2,835	4,392	4,554	9,926	5,006	3,948	2,912	1,607	1,056	1,574	3,728	3,312
22	3,521	4,500	4,143	9,302	5,261	3,956	2,230	1,764	675	3,539	3,833	2,645
23	3,885	4,393	4,109	11,103	5,312	3,137	3,623	1,885	1,020	3,728	3,717	1,567
24	3,885	3,085	3,433	9,826	4,686	2,493	3,899	1,795	1,276	3,622	2,485	2,953
25	3,898	2,489	4,615	9,467	4,938	3,336	3,936	1,542	1,449	3,664	1,640	2,095
26	3,813	4,402	6,431	9,240	3,884	3,506	3,833	1,130	1,513	3,749	3,212	1,971
27	2,563	4,634	4,994	8,395	3,759	3,474	3,791	1,849	1,449	2,719	3,585	2,860
28	1,939	4,577	4,084	7,401	4,875	3,554	2,668	1,892	1,437	1,646	3,476	3,088
29	3,286	.....	4,367	7,244	3,453	3,506	2,138	1,932	1,073	3,597	3,432	2,177
30	3,668	.....	4,245	7,271	5,010	2,354	3,724	1,622	1,124	3,873	3,456	1,464
31	3,643	.....	3,469	.....	4,920	.....	3,921	1,725	.....	3,791	.....	2,796
Total	109,314	105,640	119,019	268,802	154,807	111,681	108,541	67,465	36,635	79,090	97,665	85,802
1902.												
1	3,096	2,565	3,368	2,765	2,393	9,573	5,703	3,727	910	1,236	2,962	987
2	3,104	917	1,190	2,964	2,469	10,488	5,601	3,276	1,111	1,499	1,004	2,930
3	2,938	1,488	1,632	3,011	2,423	11,868	5,447	1,544	1,682	1,596	1,314	2,899
4	3,060	2,446	2,497	3,106	1,471	11,462	3,372	2,532	1,690	1,498	2,716	3,060
5	1,058	2,513	2,632	3,252	2,079	11,050	3,453	3,692	1,723	435	2,931	2,907
6	1,676	2,609	2,758	1,603	2,845	10,407	3,010	3,912	1,865	736	2,854	3,022
7	2,776	2,609	2,827	1,706	3,537	9,886	3,349	4,086	704	1,576	2,973	892
8	2,860	2,408	2,754	3,134	4,079	7,311	5,534	3,999	1,244	1,751	3,012	1,662
9	3,136	696	1,135	3,102	3,131	7,886	5,533	3,894	1,709	1,613	914	2,799
10	2,993	1,427	1,575	3,147	4,018	8,343	5,326	1,532	1,759	1,613	1,273	2,845
11	2,915	2,389	3,866	3,102	2,075	8,209	5,280	2,362	1,653	1,526	2,977	3,100
12	765	2,595	3,274	3,119	2,743	6,222	5,136	3,666	1,550	651	3,028	3,045
13	1,285	2,587	3,608	1,459	4,637	6,431	4,639	4,047	1,669	1,042	2,946	2,996
14	2,494	2,477	3,690	1,759	4,917	3,998	3,264	4,031	821	2,116	2,891	1,158
15	2,344	2,455	3,567	2,108	5,056	5,840	5,125	3,853	1,083	2,391	2,891	1,335
16	2,461	1,063	1,603	2,366	4,917	4,169	5,142	3,958	965	2,250	756	2,654
17	2,514	1,421	1,765	2,449	4,615	6,156	5,265	1,500	1,203	2,219	1,308	2,665
18	2,505	2,492	3,707	2,265	2,484	6,282	5,281	2,097	1,208	2,716	2,841	2,619
19	1,139	2,413	3,841	2,376	2,692	5,439	5,163	2,539	1,317	715	2,832	2,609
20	1,099	2,587	3,841	1,086	4,682	5,992	2,896	2,733	1,174	1,455	2,962	2,688
21	2,422	2,366	3,994	2,069	5,085	6,088	3,150	2,913	652	2,120	2,954	1,256
22	2,113	2,486	3,969	2,267	4,862	3,852	4,248	2,927	887	2,646	2,915	1,609
23	2,450	1,085	1,852	2,069	4,725	4,215	4,209	2,869	1,473	2,534	958	2,602
24	2,422	1,377	1,723	2,314	4,949	5,866	4,325	1,311	1,452	2,676	1,349	2,642
25	2,429	2,210	3,777	1,986	5,719	6,089	4,566	1,773	1,174	2,681	2,977	1,494
26	927	2,424	3,925	2,247	7,422	6,001	4,287	2,763	1,369	1,086	3,184	1,579
27	1,389	2,366	4,019	947	9,941	5,707	1,647	2,891	1,336	1,286	2,860	2,654
28	2,425	3,480	3,841	1,571	11,227	5,740	2,265	2,879	515	1,785	2,962	1,142
29	2,558	.....	3,926	2,381	12,317	3,491	3,441	2,789	851	2,963	3,123	1,574
30	2,425	.....	1,769	2,312	9,869	3,852	3,733	2,158	1,222	3,024	1,138	2,468
31	2,373	.....	1,735	.....	9,599	.....	4,024	1,529	.....	2,875	.....	2,587
Total	70,151	59,981	89,660	70,042	152,978	207,913	133,414	89,782	37,971	56,360	71,805	70,479

Mean daily discharge, in second-feet, of lower Fox River at Rapide Croche dam—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1903.												
1	2,587	1,675	1,829	6,192	6,009	5,677	5,571	4,393	4,195	5,312	2,664	2,819
2	2,631	2,102	1,780	6,597	6,306	6,791	5,419	2,827	4,281	5,293	2,102	3,385
3	2,587	3,008	3,191	6,806	6,145	6,069	5,278	3,011	4,298	2,805	4,674	1,915
4	1,206	3,053	3,197	7,649	4,275	5,429	3,509	3,845	4,325	2,618	4,772	3,669
5	1,479	3,097	3,453	9,297	6.118	5,386	2,055	4,136	4,324	5,321	4,769	3,628
6	2,662	3,394	3,318	7,729	5,989	5,989	2,721	3,756	1,829	4,993	4,965	1,653
7	2,818	3,387	3,665	7,661	6,237	3,747	3,943	3,707	1,936	5,826	4,929	1,973
8	2,767	1,825	2,301	6,379	6,078	4,089	3,746	3,787	3,905	5,595	1,975	3,507
9	2,832	1,837	2,070	6,342	5,911	5,812	4,093	2,206	4,708	5,339	2,098	3,621
10	2,409	3,390	3,560	6,783	3,629	5,969	3,796	2,875	4,809	5,339	4,230	3,702
11	1,559	3,581	3,981	8,283	3,964	5,564	4,009	3,671	5,077	2,845	4,957	3,595
12	1,522	3,593	4,199	7,807	5,698	6,009	1,856	4,021	5,086	2,577	5,077	3,644
13	2,954	3,652	4,064	7,402	5,467	5,735	3,370	4,134	2,734	5,340	4,731	1,623
14	3,187	3,501	3,962	8,394	5,771	3,501	4,992	4,030	2,731	5,509	4,846	1,827
15	3,610	2,005	2,550	8,517	5,467	3,818	4,684	4,134	5,199	5,482	2,226	2,964
16	3,655	2,042	2,207	6,236	5,841	5,631	5,157	1,438	5,312	5,510	1,859	3,516
17	3,493	3,368	4,178	6,216	3,421	5,668	5,149	2,003	5,293	5,434	4,219	3,694
18	1,295	3,269	4,650	6,339	3,869	5,716	5,139	4,064	5,387	2,760	4,466	3,702
19	1,953	3,285	8,437	4,188	6,088	5,354	2,700	4,099	4,442	2,957	4,888	3,677
20	3,503	3,431	6,454	4,518	6.127	5,232	3.174	4,047	3,751	5,599	4,504	2,000
21	3,476	3,468	3,887	6,429	6,127	3,326	5,047	4,021	2,489	5,134	4,282	1,916
22	3,664	2,379	1,815	6,246	5,933	3,645	4,945	1,874	5,106	5,368	1,733	3,328
23	3,436	1,749	2,340	6,657	6,157	5,429	5,102	3,869	5,369	5,293	2,307	3,424
24	3,543	3,232	5,086	5,784	3,043	5,476	5,176	1,965	5,481	5,283	4,422	1,908
25	1,293	3,107	5,055	4,796	3,824	5,411	4,918	3,794	5,415	2,590	4,484	3,353
26	1,935	3,068	4,838	3,886	6,216	5,335	2,538	4,291	5,519	2,666	3,874	1,584
27	3,289	3,457	4,839	4,376	7,378	5,204	2,189	4,449	3,481	5,133	3,310	1,319
28	3,435	3,627	4,967	6,207	6,421	2,656	4,442	4,244	2,991	5,302	3,378	2,162
29	3,527	.....	3,979	6,011	6,138	3,089	4,555	4,099	5,013	5,264	1,977	3,134
30	3,514	.....	3,337	5,288	6,657	5,084	4,254	1,781	5,059	5,217	1,873	3,619
31	3,756	.....	5,454	.....	5,199	.....	4,321	2,257	.....	5,264	.....	3,587
Total	85,577	82,582	118,643	195,015	171,503	151,841	127,848	106,828	129,635	145,268	110,591	89,448
1904.												
1	3,497	2,371	3,408	4,127	6,742	9,539	3,428	2,745	2,631	2,124	4,245	3,869
2	3,595	3,586	3,457	3,878	7,316	9,411	3,282	3,489	2,399	1,355	4,767	4,405
3	1,898	3,545	3,545	1,612	5,794	9,283	2,682	3,617	2,231	1,324	4,785	4,354
4	2,221	3,538	3,522	4,091	5,477	9,793	2,243	3,636	1,327	2,499	4,750	3,005
5	3,189	3,306	3,505	4,317	5,804	8,253	2,799	3,546	1,622	3,385	4,829	2,527
6	3,507	3,505	1,724	4,507	5,784	8,404	3,578	3,676	1,949	3,480	4,423	4,077
7	3,869	1,664	1,769	4,410	5,813	8,799	1,416	2,575	2,000	3,678	2,611	4,379
8	3,861	2,073	3,392	4,879	4,456	8,248	3,578	2,833	2,013	3,628	4,346	4,413
9	3,752	3,530	3,147	5,334	5,417	6,968	3,483	3,833	1,863	2,412	4,742	4,269
10	1,762	3,595	3,545	2,564	7,548	8,179	2,603	3,754	2,006	3,563	4,794	4,277
11	2,027	3,636	3,668	3,887	10,052	8,483	2,769	3,987	1,312	3,797	4,847	2,881
12	3,719	3,710	3,465	5,737	10,900	8,139	3,459	3,924	1,545	3,354	5,137	2,452
13	3,628	3,663	1,818	6,108	11,682	8,027	3,452	4,043	1,907	3,592	3,280	3,069
14	3,465	1,565	1,988	7,168	11,183	8,527	3,658	2,698	2,103	3,609	2,663	3,638
15	3,572	1,904	3,289	7,495	9,810	8,125	3,475	3,087	2,162	3,717	4,525	3,699
16	3,587	3,504	3,644	8,015	10,168	8,315	3,428	3,226	2,124	2,345	4,637	3,757
17	1,481	3,400	3,424	7,647	11,022	8,281	2,466	3,098	2,091	1,894	4,576	3,721
18	2,018	3,662	3,481	8,233	10,960	7,356	2,832	3,217	1,568	3,453	4,481	2,871
19	3,166	3,628	3,130	9,637	10,604	5,999	3,459	3,197	1,361	3,379	4,499	2,299

Mean daily discharge, in second-feet, of lower Fox River at Rapide Croche dam—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.												
20	3,352	3,710	1,739	9,434	10,168	5,776	3,344	3,240	1,762	4,488	2,538	3,711
21	3,329	1,689	2,036	9,399	9,574	6,167	3,206	2,214	1,825	4,470	2,286	4,439
22	3,408	2,237	3,913	9,190	8,571	5,241	3,420	1,722	988	4,248	4,102	4,354
23	3,392	3,760	4,335	9,018	9,099	3,758	3,359	2,443	1,988	3,018	4,421	4,111
24	1,185	3,962	5,185	7,436	9,845	3,617	2,345	2,531	1,888	2,915	3,264	4,077
25	2,096	4,082	7,425	7,126	10,168	2,336	2,585	2,396	1,276	4,336	3,379	2,253
26	3,668	4,134	5,429	8,823	10,812	2,336	2,909	1,551	1,381	4,694	4,285	1,812
27	3,727	3,810	2,354	9,075	9,389	2,585	3,146	2,503	1,975	4,542	2,748	3,162
28	3,869	1,843	2,504	9,028	9,527	3,474	3,498	2,595	1,925	4,575	1,667	3,709
29	3,752	2,091	3,359	9,017	8,720	3,538	3,584	2,115	2,267	6,434	3,127	3,677
30	3,848	.....	3,748	8,868	8,471	3,491	4,111	2,389	2,052	3,690	6,935	4,594
31	1,885	.....	4,385	.....	8,989	.....	2,659	2,645	.....	3,158	.....	4,311
Total	95,307	90,703	105,333	20,060	269,925	200,448	96,253	92,525	55,631	107,156	121,689	112,163

Unlike many other northern rivers the lower Fox is rarely troubled with ice gorges, because the ice on Lake Winnebago melts gradually. It is stated that trouble is sometimes experienced from anchor ice forming on the rapids in exceptionally cold weather, but this is largely prevented by the system of slack-water navigation.

The absence of great freshets prevents backwater and allows the construction of the mills out into the stream, as well as connecting sidetracks on short trestles only a few feet above the water, with perfect safety.

The bed of the river in nearly all cases is in hard limestone. Excellent quarries of fine building stone have been opened for use in both the Government and private improvements of the river.

WATER POWERS.

GENERAL STATEMENT.

No other river system in the State has so large a proportion of its total descent concentrated in its lower reaches as has the Fox. Between Lake Winnebago and Green Bay the river descends a total of 166 feet in a series of eight rapids. The total drainage area of the river is 6,449 square miles, of which area 6,046 square miles, or 94 per cent, are included above the outlet of Lake Winnebago. These two facts—the large concentration of fall in the lower river and the location of 94 per cent of its drainage area above this concentration—have the effect of producing extensive and valuable water powers.

Before any improvements had been made the river flowed between wooded clay bluffs from 10 to 70 feet or more in height, in some places rising abruptly from the river's edge on each side. Through this channel ran the clear, dashing river over its limestone bed from 300 to 1,000 feet wide. Great changes have since been made. [a]

[a] Tenth Census.

The following table gives the location and amount of fall at each of these rapids before improvement, according to surveys of Major Suter in 1866:

Rapids on lower Fox River in 1866 (before improvement). [a]

Name.	Descent.	Distance apart.
	Feet.	*Miles.*
Depere	8	.....
Little Kaukauna	8	6.0
Rapide Croche	8	6.0
Grand Kaukauna	50	4.5
Littlechute	38	2.5
Cedar rapids	10	.75
Grand Chute	38	4.0
Winnebago rapids	10	4.25
Green Bay to Lake Winnebago	170	28.0

[a] Warren, G. K., Report, 1876, p. 29.

LEGAL STATUS.

In 1846 Congress passed an act granting a large amount of land to the State of Wisconsin for the purpose of making a navigable route from Lake Michigan along Fox River to Wisconsin River. In 1853 the State, after expending $400,000 upon the improvements, passed the whole matter, including the land, into the hands of the Fox and Wisconsin Improvement Company. This company issued bonds, completed the improvement, and in 1856 the first steamer passed through from Mississippi River to Green Bay. On the advent of railroads soon after the route fell into disuse, and the company was unable to pay interest on its bonds. Suit was brought by the holders of these bonds, and the franchises, property, and land grants of the company were sold to a corporation organized in 1866 as the Green Bay and Mississippi Canal Company. In 1870 the United States appraised the value of the locks and canals at $145,000, took possession of them on the payment of this sum, and has since exercised control in the interests of navigation.

The Green Bay and Mississippi Canal Company still exists and retains its land grants, water-power franchises, and other property. The company claims the right to all surplus water after the needs of navigation are supplied. This claim includes the right to tap the canals at any point and draw off the water, provided navigation is not interfered with, as well as the right to take all the surplus flow of the river at the head of each rapids and use it at that level. This claim has been confirmed by the United States Supreme Court. The company does not claim ownership of power which is developed at a level below the head of a rapids by persons owning the land and using water which has passed the tailraces of the company.

In some cases this company owns the power, while others own the land. These interests have in some instances been mutualized in a joint company; in others protracted lawsuits have resulted in preventing the development and use of the water power up to the present time. The water powers at Rapide Croche and Little Kaukauna dams have not been improved for this reason.

As the low-water flow of the river falls far short of being sufficient for the turbines now installed, frequent controversies and lawsuits concerning the ownership of the water have resulted. Finally a few years ago the Neenah and Menasha Water Power Company, composed of practically all the users of water for power purposes on the river, was formed to regulate the use of the surplus water not required for navigation. Under the rules of the Secretary of War water may not be drawn below the crest of the Menasha dam except by

his special permit. Such permission is frequently given, however, to help out the great manufacturing interests concerned.

Fox River discharges from Lake Winnebago in two nearly parallel channels, distant about three-fourths of a mile from each other. These branches join in less than 2 miles in Lake Butte des Morts, an expansion of the river 3 miles long and extending at right angles to the general direction of the river.

Menasha and Neenah are located at the lower end of the two channels, Menasha on the north side of the northern channel and Neenah on the south side of the southern channel. These cities are about 1 mile apart and have a total population of about 12,000.

The river banks are here only 10 feet or less high. There is a dam in each channel, with an average head of 8 feet, the two maintaining the level of Lake Winnebago. These dams would develop 2,400 theoretical horsepower.[a]

The riparian owners on the Neenah channel improved the water powers before the ship canal was begun, and thus obtained a prior right under a State charter. Most of the manufactories are located on the strip of land, averaging 125 feet wide, between the river and the race.

NEENAH.

The Kimberly Clark Paper Company is the most extensive user of water power at Neenah, having installed 20 turbines under a head of 7½ feet, rated at 1,560 horsepower. In addition, this firm has 550 steam horsepower, all used in the manufacture of sulphite and ground wood pulp. The Neenah Paper Company has installed 11 turbines under a head of 7 feet, rated at 838 horsepower, and reports an additional 750 steam horsepower, all used in the manufacture of paper. The Winnebago Paper Mills have installed turbines under a 9-foot head, rated at 854 horsepower, which is supplemented with 450 steam horsepower.

Other power users in Neenah are included in the following table:

Additional water powers at Neenah.

Owner and use.	Turbines.		Steam H. P.	Remarks.
	Head.	H. P.		
	Feet.			
Kreuger & Lachmann, flour	8.0	469	125	
Neenah Boot and Shoe Manufacturing Co	8.0	39	12	Use steam when water is cut off.
Neenah and Menasha Gas and Electric Light Co.	7.5	199	125	
Robert Jamison, machine shop	8.0	94	10	
Wulff, Clausen & Co., flour	8.0	123	60	Burned.

MENASHA.

The Government canal is located at Menasha. This canal has a total length of about 4,320 feet, its single lock being located at the lower end, near Lake Butte des Morts. This dam develops 2,487 theoretical horsepower at ordinary flow. The Federal Government entered into an agreement with certain persons under which they constructed the navigation improvements and received in return the ownership of the resulting water powers. As a consequence the Green Bay and Mississippi Canal Company has no interest in these water powers.

A dam 475 feet long at the head of the canal develops a head of 8.2 feet, though some of the turbines work under heads of 6 to 8 feet. The strip of land between the canal and river is used for the location of numerous manufacturing plants, all the power, except that of the Howard Paper Mill, being taken from the canal.

[a] This estimate is based on an ordinary discharge of 2,660 second-feet, equal to a run-off of about 0.43 second-feet per square mile.

The largest water-power user at Menasha is the George A. Whiting Company, which owns the right to "first-class water." Its 6 turbines work under an average head of 8 feet and are rated at 503 horsepower. The company, which is engaged in the manufacture of paper, has also installed 265 steam horsepower.

Another large concern is the Menasha Wooden Ware Company, whose turbines work under an average head of 5 feet and are rated at 414 horsepower. This is supplemented by 1,090 steam horsepower.

The other important water-power users in Menasha are included in the following table:

Additional water powers at Menasha. [a]

Owner and use.	Turbines.		Steam H. P.	Remarks.
	Head.	H. P.		
	Feet.			
Gilbert Paper Co.	5	243	800-1,000	
Howard Paper Co.	5	321	200	
John Strange Paper Co.	5	156	250	Leased.
Banner Flouring Mills	5	90	50	
MacKinnon Excelsior Co.	6	124	225	
MacKinnon Pulley Co.	6	25	25	
John Schneider, planing mill	6	124	.....	
Valley Knitting Co., hose, mittens, etc.	4	38	.....	
Menasha Woolen Mills	5	35	Small engines.	When water is low.

[a] Authority, L. M. Mann, United States assistant engineer.

For the entire distance of 5 miles between Menasha and the Appleton upper dam the river affords slack-water navigation; indeed, it has been claimed that later improvements on the Appleton dam have caused the water at Menasha to back up a foot or more above its original level. As Appleton is approached the clay banks rise to a height of 50 or 60 feet.

APPLETON.

Fall.—Because of their intrinsic value, as well as on account of their early development, the Appleton powers are not excelled on the lower Fox. According to the Government profile the river has a total fall of 36.7 feet in a distance of 1.2 miles. This head is developed by three dams, which divide the river into upper, middle, and lower levels, with estimated theoretical horsepower [a] at ordinary flow of 4,238, 2,225, and 2,558, respectively.

At Appleton the river by a gradual bend changes its course from northeast to southeast, again turning to the northeast just above the lower dam. On the left bank the clay bluffs rise steeply 50 to 70 feet, while on the opposite bank is a flat extending for 3,500 feet, and perhaps 1,300 feet wide, beyond which rise high bluffs, as on the left bank. For the purposes of navigation the Government has constructed two dams, dividing the descent into two levels. The second or middle dam was constructed by private enterprise and is used exclusively for water power.

Upper dam.—The upper dam is a substantial stone structure. It extends from the foot of State street on the left bank normal to the shore for 250 feet, thence diagonally downstream for 700 feet to a point 400 feet from the right bank. From this latter point a retaining wall or long pier extends downstream 800 feet to the right bank. The head varies from about 10 feet at the upper end of the dam to 18 feet at the lower end, the average, as given by the Government engineers, being 14 feet. Its available water power is taken from a race along the left bank, from the ship canal on the right bank, and from the adjacent retaining wall.

[a] Estimated by U. S. Asst. Engr. L. M. Mann, on flow of 170,000 minute-feet, at 4,508, 2,367, and 2,721.

The extreme variation of head is stated at 2 feet, but the ordinary variation is only half that amount. It is due to the manner of using water by the Neenah mills, and to the prevalence of strong winds blowing continuously on Lake Winnebago and changing its volume of discharge.

The race on the left bank is 600 feet long, several extensive paper, pulp, and flouring mills occupying the strip of land between it and the river. Here are located the Appleton Paper and Pulp Company, with installed turbines under 11-foot head, rated at 550 horsepower; the Kimberly & Clark Company; the Vulcan and Tioga mills, with about 710 and 770 turbine horsepower, respectively; and the Atlas paper mill, with 766 turbine horsepower. The Appleton Waterworks Company, 1,400 feet below, receives power from this canal through a flume which affords a head of 18 feet. The above powers by long-established usage are recognized as belonging to the respective companies, and not to the Green Bay and Mississippi Canal Company.

Of the power developed on the right bank, nearly all is taken from the long pier. The Green Bay and Mississippi Canal Company owns the land on this side of the river and leases power to users.

The head here varies from 12 feet near the upper end of the pier to 16 feet at the lower end. The water is taken through ten arched openings in the stone pier from the large bay above. This power is fully developed by the Wisconsin Traction, Heat, Light, and Power Company, with turbines under 16-foot head, rated at 2,250 porsepower (besides 2,000 steam horsepower).

Of the few unused power sites on this dam the greater number are located on the ship canal, and, as heretofore stated, are owned by the Green Bay and Mississippi Canal Company. The following table gives the developed powers:

Water powers on the United States canal at Appleton.

Owner and use.	Water power.			Steam H. P.
	Average head.	Rated H. P.	Entitled to—	
	Feet.			
Riverside Paper and Fiber Co	14.0	383	300	.....
Appleton Chair Co., furniture	7.5	26	25	35
Union Toy and Furniture Co	8.0	50	25	30

Middle dam.—The middle dam also is independent of both the Government work and the Green Bay and Mississippi Canal Company. It was built by private capital for water-power purposes only. It is 2,400 feet below the upper dam and is about 450 feet long. The dam was constructed of timber in 1877 and has its foundation in limestone. A canal leads down the north (left) bank. The south end of the dam abuts on Grand Chute Island, West's hydraulic canal being supplied from the adjacent basin.

Previous to 1877 power had been developed by wing dams passing upstream from both banks for several hundred feet. The present dam is reported to have an average head of 73 feet, developing at ordinary flow (2,660 second-feet) 2,190 theoretical horsepower. The head at the various factories and mills varies from 7 to 14 feet, depending on their location, the variation being similar to that at the upper dam. The water level is remarkable for uniformity.

The north-shore race is 800 feet long, supplying a head varying from 9 feet at the upper end to 12 feet at the lower.

West's canal starts at the right abutment of the dam and extends down Grand Chute Island for about 1,700 feet, nearly parallel to the river. It has a width of about 100 feet, with earth and stone embankment about 3 feet above the water surface. The head averages 10 feet. Several fine power sites still unoccupied on this canal are especially desirable because of excellent transportation facilities.

The following table gives the important users of water power from the middle dam:

Water powers on the middle dam, Appleton.[a]

Owner and use.	Water power.			Steam H. P.
	Average head.	Rated H. P.	Entitled to—	
Fox River Paper Co.:[b]	*Feet.*			
Ravine mill	11.0	2,126	⅓ flow of Fox River less 25 H. P.	1,050
Lincoln mill				
Fox River mill				
Patton Paper Co.	8.0	814	1,250 H. P	500
Patton Pulp Co.				
Telulah paper mill, pulp	8.5	465	3,000 sq. in.	500
	14.0	903		
Appleton Machine Co.	5.0	14	500 sq. in.	25
Appleton woolen mill, paper, knitting, etc.	5.0	47	90 H. P.	50
Fourth Ward planing mill, lumber	8.0	28	30 H. P.	.....
Marston & Beveridge, hubs and spokes	8.0	77	75 H. P.	.....
Valley iron works	7.0	47	40 H. P.	.....

[a] Authority, L. M. Mann, U. S. assistant engineer.
[b] Power used by Fox River Paper Co. (three mills) are located on West's canal; the other powers are on the left bank.

Lower dam.—The lower or Government dam is located about three-fourths of a mile below the middle dam and just below the lower bend of the river, at a point where the river is 485 feet wide. The dam extends downstream from the left bank 417 feet, at an angle of about 45° with the channel, to an embankment which extends 600 feet farther downstream. The lower-level ship canal is back of this embankment. The river runs close to the left bank, which is high and steep, while on the right bank a flat 200 to 300 feet wide intervenes between the shore and the bluffs. There are four methods of utilizing the power—viz, from the abutment of the dam, from the race on the left bank, from the ship canal, and from the Telulah Water Power Company's canal on the right shore. The average head of this dam is stated at 8.5 feet, which at ordinary flow gives 2,550 theoretical horsepower. The report of Capt. L. M. Mann, on whose authority the above statement is made, shows that about 850 horsepower remain to be installed. There is said to be a fall of 3 feet in the 1,500 feet below the dam. This water power is owned by the Green Bay and Mississippi Canal Company.

The left or west-shore race starts at a point 450 feet above the dam and extends nearly parallel to the channel a distance of 1,200 feet below the dam. The bluffs rise steeply from the water, so that mills must extend out over the river. It is claimed that this race is entitled to one-fourth of the stream flow.

The right or east canal, known as the Hyde & Harriman canal, has several good locations for mills. The land adjacent was owned by Mr. W. Hyde and Judge J. E. Harriman, while the power belonged to the Green Bay and Mississippi Canal Company. These interests were united and the canal completed in 1880. It starts at the head of the ship canal and skirts the bluffs for its entire length of 2,250 feet, leaving a wide strip of flat land between it and the river. An earth embankment forms the river side. The cross section of the canal at its upper end is 120 by 7 feet, but it gradually decreases. Its head varies but slightly and is said to average 10 feet. The most important mill on this canal is that of the Telulah Paper Company, with a total of 11 turbines, rated at 1,368 actual horsepower.

CEDARS DAM.

This dam backs up the water for the entire distance of 3.3 miles to the lower Appleton dam, affording slack-water navigation. Fox River in this stretch is hemmed in by

high clay banks and has an average width of 600 feet. At a short distance below the dam however, a small creek enters from the north, causing the bluffs to recede from the river and follow up the creek, leaving a flat area of perhaps 35 acres. The dam is situated about 1,000 feet below the point where the bluffs leave the river. It crosses the river in a normal distance of 810 feet. It has an average head of 9.7 feet, which at an ordinary flow of 2,660 second-feet gives 2,910 theoretical horsepower. This power is owned by the Green Bay and Mississippi Canal Company, but the entire power is leased to the Kimberly & Clark Paper Company for a paper mill. This firm reports an installation of 33 turbines, under a head of 11 feet, rated at 4,217 actual horsepower.

LITTLECHUTE.

The next Government dam is located 4,000 feet below the Cedars dam at a small village called Littlechute. The river has extensive rapids at this point, there being a total descent, according to the Government profile, of 36.2 feet in the 2 miles between the foot of the Cedars lock and the backwater of the Kaukauna dam below. These rapids are passed by a canal 6,500 feet long on the left bank of the river. One lock of 16-foot lift is located about 1,000 feet from the head of the canal, and a composite lock of about 20-foot head is located at the lower end of the canal.

The river is about 840 feet wide at the dam site. On the left bank the bluffs retreat from the river slightly, leaving a narrow flat and some small islands. On the right bank there is a break of perhaps 1,500 feet in the bluffs. This power and the adjacent land belong to the Green Bay and Mississippi Canal Company. The dam has a head of 12 feet, but the total available head, because of the adjacent rapids in the 7,000 feet below the dam, is stated to be 34 feet. This descent, with a flow of 2,660 second-feet, gives 10,200 theoretical horsepower. It is certain that to develop more than half this amount would require a large expenditure of money. At the present time 20 feet of fall have been developed.

The Littlechute Pulp Company has installed 24 (mostly 54-inch) turbines under a head of 12 feet, rated at 3,000 actual horsepower. The power next in importance on this dam, and the only power not leased from the Green Bay and Mississippi Canal Company, is that of a flouring mill owned by Arnold Verstigen, run by 6 turbines rated at 100 horsepower.

COMBINED LOCKS DAM.

About a mile below the Littlechute dam is the Combined Locks dam, owned by the Combined Locks Paper Company. A view of this dam, together with part of the company's plant, is shown in Pl. II, *B*. The company has 49 turbines installed, rated at 4,438 practical horsepower, leased from the Green Bay and Mississippi Canal Company.

GRAND KAUKAUNA DAM.

A descent of 50.3 feet in a distance of less than a mile entitles the Grand Kaukauna rapids to first place in all the water powers of the lower Fox River. Both topographic and transportation conditions are very favorable for improvement. The Kaukauna dam is distant 2.5 miles from the Littlechute dam and produces slack water to the end of the Littlechute canal. The rapids are passed by a ship canal 7,400 feet long, extending from the dam and including 5 locks with an aggregate lift of 50.3 feet, all located on the left bank of the river. At its middle point this canal is distant 1,000 feet from the river. The river is about 700 feet wide at the dam, but a quarter of a mile below broadens out between several islands to a maximum width in the middle of the rapids of over 2,000 feet. The islands are low, but all have the limestone base. These islands, together with the flats on both sides of the river, give fine facilities for water-power development. The distance across the valley from bluff to bluff is about 3,500 feet.

The water powers are made available in three or more ways, viz, from the ship canal, from the Kaukauna Water Power canal, and from the Edwards & Mead canal. There is

A. DAM ON LOWER FOX RIVER AT DEPERE.

Looking east.

B. COMBINED LOCKS DAM ON LOWER FOX RIVER AT LITTLECHUTE.

Private dam; plant cost $1,250,000.

frontage of 900 feet or more on the upper level of the ship canal suitable for power ·velopment and furnishing an average head of about 16 feet. The Kaukauna Water ›wer canal starts 400 feet above the dam, thence runs 400 feet at an angle from the shore about 45°. At a point about 200 feet from the river it turns and runs parallel to the uth channel of the river for 2,000 feet. Its greatest width, 150 feet, is at the bulkhead. s minimum width is 86 feet and its depth is 11 feet. There is said to be a descent of 2 et in the total length of 2,400 feet, and the average head furnished is 18 feet. Along e side and end of the canal there is a total frontage of 2,100 feet available for power tes and mills.

The Kaukauna Water Power Company's claims to one-half the flow of the river were ›nied by the Green Bay and Mississippi Canal Company at the time of the construction these improvements, and the matter was taken into the courts for adjudication. After ccessive trials in the State courts the question was finally settled by the United States ıpreme Court October, 1898, in favor of the Green Bay and Mississippi Canal Company, hich thereupon purchased the entire plant and canal of the Kaukauna Water Power ›mpany.

In this decision the Supreme Court held broadly that the use of the surplus waters cre-ed by the Government dam and canal at Kaukauna belonged to the Green Bay and ississippi Canal Company, but that "after such waters had passed over the dam and rough the sluices and had found their way into the unimproved bed of the stream, the ghts and disputes of the riparian owners must be determined by the State court."

The Edwards & Mead canal was built under the direction of Capt. N. M. Edwards, engi-er for the Green Bay and Mississippi Canal Company. Advantage was taken of a branch the main north channel running between two large islands; this was formed into a pocket v damming the ends and sides. This channel starts 600 feet below the bridge, and the ım was placed 1,000 feet below its head. As the water is taken from below the first vel of the rapids the Green Bay and Mississippi Canal Company could make no legal aim to it, but subsequent to its development bought the power. The sides of the ıannel are substantially built of earth on the south side and dry rubble masonry on the ›rth side.

Recently very comprehensive plans have been prepared for the improvement of the lower vel at Kaukauna, which will produce 6,500 theoretical horsepower. These plans include e blasting out of the tailrace so as to develop a 21-foot head at the present Government ım, and also the construction of a new masonsy dam below which will develop 27 feet lditional. As this dam would render useless some of the present improvements below e Government dam, it will be necessary to purchase such property before the new dam ın be constructed. These developments will be made as soon as a suitable tenant is ›und.

At the present time the Green Bay and Mississippi Canal Company offers for rent 3,000 eoretical horsepower already developed at the headrace of the Kaukauna WaterPower ompany's canal, recently purchased. Large store buildings at this point, though par-ally destroyed by fire, could readily be converted into a large manufacturing plant.

The city of Kaukauna has 5,000 inhabitants and is on the main line of the Chicago nd Northwestern Railway, being also reached by the Fox River Valley Electric Railway.

The following table gives a list of the power users at Kaukauna and the installed turbine power:

Water powers on Fox River at Kaukauna. [a]

Owner.	Water power.			Steam H.P.
	Average head.	Rated H. P.	Entitled to—	
	Feet.			
Badger Paper Co	16	1,230	.....	450
Chicago and Northwestern Rwy. shops	7	47	75	110
Kaukauna Fiber Co	14	194	100	200
Kaukauna Machipe Co	14	250	75	15
Kaukauna Electric Light Co	14	194	.....	160
Thilmany Pulp and Paper Co	14	389	275	175
Western Paper Bag Co	15	1,400	400	310
Outagamie Paper Co	21	816	1,500	.....
Lindauer Pulp Co	12	.....	.....	.....
Reese Pulp Co	12	440	.....	350
Thilmany Pulp and Paper Co	12	709	.....	567

[a] Nos. 1-4 are owned jointly by the Green Bay and Mississippi Canal Company; Nos. 5-9 are leased from the same company; Nos. 10 and 11 are leased from same company and Edwards.

Below Kaukauna Rapids the river is from 1,200 to 2,200 feet wide for nearly 2 miles, but it gradually contracts to a width of about 500 feet for the lower half of its course between Kaukauna and Rapide Croche. Almost without exception the bluffs rise directly from the river for the entire distance. Navigation is also by slack water from the Grand Kaukauna Canal to the Rapide Croche dam.

RAPIDE CROCHE DAM.

The Rapide Croche dam is located 4.5 miles below the Grand Kaukauna dam and was built by the Government for navigation purposes. It is about 450 feet long and has an average head of 8.5 feet. The bluffs rise on either side close to the river, except on the left bank at the site of the ship canal. This canal starts just above the dam and extends downstream for a distance of 1,760 feet to the lock. This forms a strip of land well suited for power or mill sites, being 900 feet long and varying in width from 20 feet at the ends to 200 feet at the middle. This ground and 120 acres adjacent is owned by the Green Bay and Mississippi Canal Company.

The Rapide Croche dam develops 2,400 theoretical horsepower, which may be leased on extremely favorable terms. At the present time this power is not utilized. Its location, nearly midway between Green Bay and Appleton, is convenient for the development of electric power for railroad or other purposes. The Chicago and Northwestern Railway and the Fox River Valley Electric Railway are close at hand on the left bank.

LITTLE KAUKAUNA DAM.

Six miles below the Rapide Croche dam is located another Government dam which furnishes slack-water navigation in this stretch of the river. This dam is about 550 feet long and furnishes a head of 8 feet. The bluffs rise close to the right bank, but on the left bank recede for several hundred feet. Advantage is taken of this fact to locate the Government canal here. This canal is 950 feet long and has a single lock at its lower end.

The power here, like that at Rapide Croche, is owned by the Green Bay and Mississippi Canal Company, while the riparian rights are owned by other parties. This fact has led to a protracted legal struggle, which has resulted in preventing the utilization of the valuable water powers. It is stated on good authority that these suits have recently been settled and that improvements will soon be made.

number of water-power lots would be made available by the construction of a .rallel to the canal about as shown in fig. 3. An 8-foot head with a flow of 2,660 t, gives 2,400 theoretical horsepower.

DEPERE DAM.

n at Depere, a city of over 4,000 inhabitants, about 7 miles from the mouth of , is the last dam and lock on the river. A view of it is shown in Pl. II, *A*. The :rib construction, about 2,000 feet long, and furnishes an average head of 7 feet, an ordinary flow of 2,660 second-feet, gives 2,100 theoretical horsepower. A eel bridge is located just below the dam.

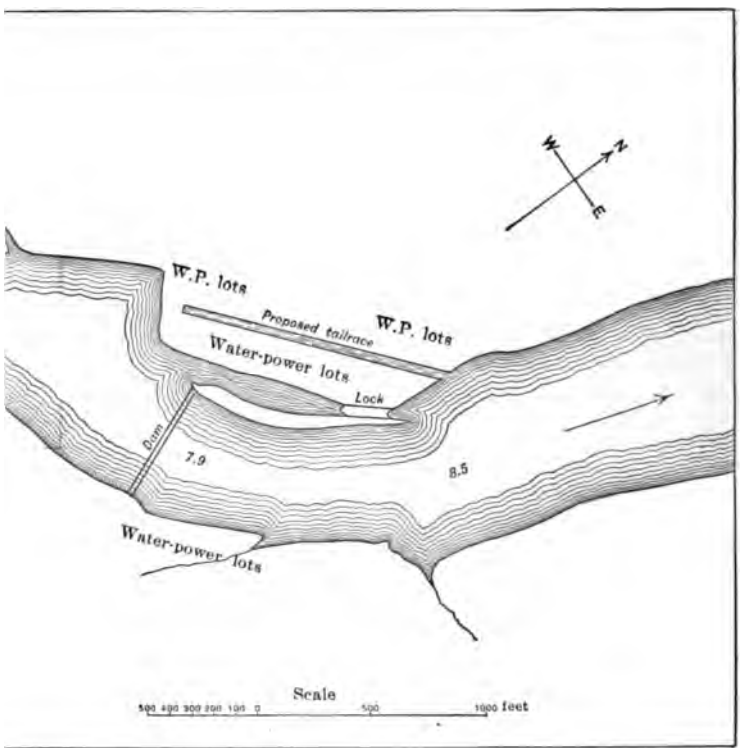

FIG. 3 Plan of water-power development at Little Kaukauna, Wis.

ver does not belong to the Green Bay and Misssisippi Canal Company, for it was r a contract whereby the riparian owners were to have the use of the power in the maintenance of navigation improvements.

erican Writing Paper Company, which has one of the largest and most modern s on the river, has installed 16 large turbines, with a rating of 1,565 practical r. In addition the company uses 1,300 steam horsepower. It is entitled to ower of the river less 290 horsepower. The value of its annual product is stated 0.

right bank, taking water from the ship canal, are located the J. P. Dousman s flouring mill, with 175 actual turbine horsepower, and the Depere Electric Light : Company's plant, with 100 actual turbine horsepower. The flouring mill has of 300 barrels a day. These are the last powers on the river.

RAILROADS.

Attention has elsewhere been called to the fact that the freedom from freshets which lower Fox River enjoys allows the building of railroad side tracks over or across the river so as to reach any mill no matter how situated. The river thus enjoys excellent railroad facilities. The Chicago and Northwestern Railway closely follows the left bank of the river between Neenah and Green Bay, and a branch performs a similar service for all the mills between Menasha and Kaukauna on the right bank. The Chicago, Milwaukee and St. Paul Railway reaches Neenah, Menasha, and Appleton, while another branch parallels the river between Green Bay and Depere. The Wisconsin Central line reaches Neenah and Menasha. Besides the steam lines, the river's entire length is closely followed by an electric interurban railroad, which provides a train every hour at reduced rates.

The navigation improvements maintained by the Federal Government provide for a 6-foot channel between Oshkosh and Green Bay. While this channel is insufficient for the larger freight boats navigating the Great Lakes, the commerce on lower Fox River has been sufficient to reduce the railroad freight rates to an exceedingly reasonable basis. This gives the numerous factories on this river a very marked advantage in shipping both raw materials and finished products. This advantage, together with the extremely low rates at which water power may be rented ($5 to $10 per annum per horsepower), has already made this one of the largest manufacturing districts in the State.

MENOMINEE RIVER SYSTEM.

This river is formed by the junction of Michigamme and Brule rivers, and for its entire length of about 104 miles forms the boundary between Wisconsin and Michigan. It flows in a general southeasterly direction, entering Green Bay at Marinette.

DRAINAGE.

The Menominee drainage basin is narrow in its lower portion, but widens as the stream is ascended, the river receiving important branches near its source. Its total drainage area is about 4,000 square miles, of which 1,450 square miles is in Wisconsin.

Like Chippewa River, it has a main arm to the north, Michigamme River, which is nearly as long as the main river, its source, in fact, being within 12 miles of Lake Superior. This has an important bearing on the discharge of the Menominee, because it secures the large run-off due to the heavy precipitation of that region as well as the steadying effect of the enlarged drainage. The combined drainage area of Brule and Michigamme rivers amounts to 1,769 square miles [a]—nearly one-half that of the entire river system.

PROFILE.

From its head, at the junction of Brule and Michigamme rivers, to its mouth, a distance of about 104 miles, the river descends about 700 feet. In addition to this its Wisconsin tributaries descend about 300 feet, and those in Michigan 470 feet. The opportunities for water power are numerous, because of the frequent concentrations of descent in rapids along the entire course of the river. The following descriptions of the most important water powers are taken from data furnished by Messrs. O'Keef & Orbison, hydraulic engineers, of Appleton, Wis., who also loaned maps and profiles of the river, and from the very full descriptions by James L. Greenleaf, C. E., in the census report.[b]

Quoting from the latter:

> It will be evident from the following account that there is an immense amount of water power on the Menominee awaiting development, the concentrations of the descent in numerous rapids and falls supplying remarkably fine opportunities for improvements. Any works for the utilization of the power would have to be so constructed as not to interfere with the manufacturing company in the driving of logs, but dams, etc., could be built so as to be no hindrance to the passage of logs.

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[a] Tenth Census, vol. 17, p. 57.
[b] Water powers of the Northwest: Tenth Census, vol. 17, pp. 59–60.

In the table that follows will be found a statement in detail of the descent of Menominee River, together with other valuable data:

Profile of Menominee River from its mouth to head of upper rapids, Twin Falls.[a]

No.	Station.	Distance— From mouth.	Distance— Between points.	Elevation above sea level.	Descent between points. Total.	Descent between points. Per mile.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
1	Mouth of river			580.0		
2	Dam No. 1, foot	2.0	2.0	580.0		
3	Dam No. 2, foot	2.5	.5	587.0	7.0	14.0
4	Dam No. 3, foot	2.75	.25	594.0	7.0	28.0
5	Schappies rapids, foot	7.7	5.0	612.0	18.0	3.6
6	Schappies rapids, head	8.7	1.0	622.0±	10.0	10.0±
7	Grand rapids, foot (mouth of Little Cedar River)	22.0	13.3	649.0±	27.0	2.0±
8	Grand rapids, head (NW. ¼ sec. 32, T. 34 N., R. 23 E.)	24.5	2.5	669.0±	20.0	8.0
9	Railroad crossing, Ross	26.5	2.0	671.8	2.8	1.4
10	White rapids, foot (lot 1, sec. 30, T. 35 N., R. 21 E.)	50.7	24.2	683.4	11.6	48.0
11	White rapids, head (south line sec. 7, T. 35 N., R. 22. E.)	53.7	3.0	714.4	31.0	103.0
12	Pemena rapids, foot (mouth Pemena Creek)	61.5	7.8	748.3	30.3	3.9
13	Pemena rapids, head (south line sec. 5, T. 36 N., R. 22 E.)	63.0	1.5	767.1	18.8	12.5
14	Pemena dam, foot	67.0	4.0	773.1	6.0	15.0
15	Pemena dam, crest	67.5	.5	786.2	13.1	26.2
16	Sturgeon Falls, foot	77.0	9.5	803.9	17.7	1.9
17	Sturgeon Falls, head	77.5	.5	816.8	12.9	25.8
18	Sturgeon River, mouth	78.1	.6	818.0	1.2	2.0
19	Norway, Mich. (where public road joins river)	80.1	2.0	824.0	6.0	3.0
20	Iron Mountain, Mich. (500 feet above old ferry)	84.1	4.0	851.0	27.0	6.7
21	Little Quinnesec Falls, foot	85.4	1.3	878.0	27.0	20.7
22	Little Quinnesec Falls, head	85.65	.25	942.0	64.0	256.0
23	Big Quinnesec Falls, foot	89.9	4.25	966.0	24.0	5.6
24	Railroad bridge south of Iron Mountain	91.15	1.25	1,020.0	54.0	43.3
25	Highway bridge south of Iron Mountain	92.4	1.25	1,045.0	25.0	20.0
26	Railroad bridge, river siding	100.4	8.0	1,065.3	20.3	2.5
27	Twin Falls (500 feet below lower rapids)	101.4	1.0	1,072.5	7.2	7.2
28	Twin Falls (head of upper rapids)	102.1	.7	1,099.8	27.3	3.9

[a] Authority: No. 1, U. S. Lake Survey; Nos. 2-6, Menominee River Boom Company; Nos. 7, 8, and 10-18, T. W. Orbison; No. 9, Wisconsin and Michigan Railway; Nos. 19-27, U. S. Geol. Survey; No. 28, Chicago and Northwestern Railway.

GEOLOGY.

While the surface is largely covered, generally deeply, by glacial drift, the Menominee and all its tributaries flow over hard, pre-Cambrian crystalline rocks as far south as the mouth of Pike River, or fully two-thirds its length. In this region important iron mines are found. Below the mouth of Pike River the Menominee flows 10 miles across the Cambrian sandstone, then for 18 miles across the next higher layer, the "Lower Magnesian" limestone, and for the last 8 miles to its mouth across the "Trenton" group of limestones.[a]

The crossing of the Cambrian sandstone results in no rapids of importance, but two rapids occur in passing the "Lower Magnesian" and the "Trenton" limestones. Most of the rapids, of course, are in the harder crystalline rocks above the mouth of Pike River.

The topography of the country through which Menominee River flows can not be described as mountainous, but many high ridges give diversity to the surface. The Wisconsin branches, Pine and Brule rivers, rise side by side with the Flambeau and the Wisconsin in

[a] Geol. Wisconsin, p. —.

a high, flat plateau, abounding in lakes and swamps. In many cases the rivers head in lakes but a few rods apart, or even in the same swamp. These lakes and swamps have an elevation of nearly 1,600 feet above sea level, or 1,000 feet above Lake Michigan. The Michigan branches flow from a similar though even higher region, and it is certain that these swamps and lake reservoirs exert a marked influence in steadying the discharge of the river.

RAINFALL AND RUN-OFF.

Because of the paucity of data concerning the discharge of rivers in this region, it is exceedingly difficult to estimate the ordinary discharge. The discharge measurements in this district have been made since 1901, and most of them since 1903.

The rivers mentioned below are similarly situated with respect to Lake Superior, which is perhaps the governing factor in determining the rainfall. In 1903 Escanaba River yielded a minimum of 700 second-feet from 891 square miles. Measurements made by the I. Stevenson Company indicate a minimum flow of this river, in a dry year, of 400 second-feet. Measurements of Iron River, continuing from November, 1901, to April, 1904, show a minimum flow of 0.8 second-foot per square mile for two months in 1902, and the same for February, 1903. It seems reasonably certain that except in unusually dry years the ordinary low-water discharge of these rivers is not far from 0.6 second-foot per square mile. In 1904, a year of average rainfall, the minimum run-off occurred in the month of December, when it averaged 0.77 second-foot per square mile.

In the following tables will be found the maximum, minimum, and mean discharge in second-feet of Menominee River at Little Quinnesec Falls during twelve months of 1898 and 1899:

Estimated monthly discharge of Menominee River at Little Quinnesec Falls, Wis.[a], May, 1898, to August, 1899.

[Drainage area, 2,432 square miles.]

Date.	Discharge.			Run-off.	
	Maximum.	Minimum.	Mean.	Per square mile.	Depth.
1898.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Inches.*
May	3,802	2,443	3,086	1.26	1.45
June	3,616	1,447	2,459	1.01	1.13
July	2,740	655	1,439	.59	.68
August	4,968	498	2,282	.94	1.08
September	3,544	797	2,566	1.05	1.17
October	5,735	1,947	3,248	1.34	1.54
November	3,601	1,484	2,766	1.14	1.27
1899.					
April	4,642	3,083	4,011	1.65	1.84
May	4,485	3,744	4,112	1.69	1.95
June	4,624	2,017	3,476	1.43	1.60
July	2,521	804	1,819	.75	.86
August	1,789	1,408	1,573	.65	.75

[a] For the daily discharge for this time see Water-Supply Paper No. 83, pp. 256–257. Measurements were made by J. H. Wallace, C. E., and furnished by Kimberly & Clark, of Niagara, Wis.

It will be seen that the smallest monthly average during this time was 0.59 second-foot per square mile of drainage. Lumbering operations on Menominee River, though declining since 1892, are still active. The operation of the many logging dams must have a great effect on the regimen of the river. In a few years the lumber will be so nearly removed that it will be cheaper to carry logs by railroad. Then the dams can be used to augment the low-water flow. This will greatly enhance the value of the water powers.

The average annual rainfall of this region is estimated by the Tenth Census at 35 inches, or 10 per cent in excess of the average of the State.

The following table gives the annual precipitation in the valleys of Wolf, Oconto, Peshtigo, and Menominee rivers for the eleven years ending in 1904:

Annual precipitation, with averages, at seven stations in Wisconsin covering eleven years.

Station.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.	1904.	Average.
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Inches.*
Amherst	.....	.....	35.1	30.2	28.7	30.2	37.6	.....	32.1	.....	30.2	34.7
Koepenick	23.8	24.9	32.2	25.5	28.1	31.3	46.6	33.0	27.7	42.9	43.0	32.6
Florence	27.6	27.2	29.2	25.7	27.5	34.3	37.9	32.7	.....	43.3	.....	31.7
Oconto	29.8	29.9	36.0	28.1	29.7	26.4	38.0	28.1	29.3	34.1	34.7	31.3
New London	.....	.....	.....	27.4	29.0	.....	35.6	28.1	34.3	28.8	31.1	30.8
Shawano	27.9	.....	32.8	25.3	25.3	27.9	39.3	.....	.....	.....	.....	29.8
Waupaca	.....	.....	33.6	26.5	24.3	32.4	.....	26.0	30.8	32.0	32.0	29.7
Average	27.3	27.3	36.3	27.0	27.5	30.8	39.1	29.6	30.8	36.2	34.2	31.5

The summary given above, embodying observations of the yearly rainfall from 1894 to 1904, inclusive, at seven near-by stations, shows the average rainfall of this section for the above period to be 31.5 inches. This is very conservative, for earlier observations for longer periods show larger averages, as will be seen from the following:

Record of precipitation at two stations in Wisconsin prior to 1894.

[From the Smithsonian tables.]

Station.	Period covered.	Precipitation.
	Years.	*Inches.*
Embarrass	35	38.3
Weyauwega	12	44.1

There is reason to believe that the rainfall at the headwaters of these rivers is in excess of that on the lower part of the drainage area, where most of the observation stations are located.

The following table compiled from Bulletin C, United States Weather Bureau, shows

the result of observations of precipitation and temperature in the basins of Fox, Oconto, Menominee, and Wolf rivers for the years stated prior to 1876:

Record of precipitation and temperature at nine stations in Wisconsin prior to 1876.

Station.	Period of observation.	Precipitation.					Temperature.	
		Spring.	Summer.	Autumn.	Winter.	Year.	Summer.	Winter.
		Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*° F.*	*° F.*
Wautoma	1871-1874	5.50	6.25	1.98	3.16	25.92	.....	.....
Portage	1836-1845	5.58	11.46	7.63	2.83	27.50	68.22	19.81
Weyauwega	1861-1873	6.74	17.85	14.23	5.31	44.13	68.20	19.32
Waupaca	1867-1874	5.50	14.50	6.92	3.93	25.92	70.17	20.48
Menasha	1857-1858	6.83	10.73	7.06	5.14	29.76	65.30	23.11
Appleton	1856-1871	7.65	10.24	6.92	3.70	28.51	67.48	20.15
Green Bay	1858-1865	6.18	9.35	10.43	4.46	32.42	68.10	18.62
Embarrass	1864-1874	8.14	12.49	8.21	5.73	34.57	66.82	18.25
Escanaba	1872-1876	8.52	13.72	10.57	3.28	36.09	.....	.....

It will be noted that the upper portion of this drainage area is scarcely represented in the above tables, the stations where rainfall observations were made being grouped in the lower portion of the river valleys. There is reason to believe that the average rainfall would be found to be sensibly larger for a series of stations more evenly distributed so as to include the northern portion.

The following discharge measurements, gage heights, and rating table are the result of observations by hydrographers of the United States Geological Survey on Menominee River, near Iron Mountain, Mich.:

Discharge measurements of Menominee River at Homestead bridge, near Iron Mountain, Mich., 1902 to 1905.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
1902.		*Feet.*	*Sq. feet.*	*Ft. pr. sec.*	*Feet.*	*Sec-feet.*
September 4	Horton and Gregory	.....	.....	.....	1.90	1,322
November 4	W. V. Savicki	.....	.....	.....	2.67	1,584
1903.						
April 9[a]	L. R. Stockman	202	1,532	2.22	5.40	3,409
April 19	do	.....	2,000	2.78	7.32	5,570
July 22	do	208	1,455	2.17	4.20	3,161
August 25	do	208	1,342	1.76	3.60	2,357
September 16	do	212	2,875	[b] 3.41	10.38	9,490
October 27	do	205	1,477	1.93	3.99	2,856
1904.						
May 18	E. Johnson, jr	210	2,312	2.68	7.95	6,193
June 1	do	210	2,522	3.01	8.97	7,591
August 10	do	205	1,101	1.42	2.06	1,558
September 5	do	210	1,571	2.02	4.34	3,175
October 11	F. W. Hanna	225	2,408	3.20	8.25	7,716
November 18	E. Johnson, jr	210	1,511	1.94	4.02	2,925
1905.						
April 12	S. K. Clapp	220	2,271	2.90	7.43	6,588
May 22	do	215	2,035	2.32	6.85	4,718
June 15	M. S. Brennon	208	1,421	1.78	3.67	2,524
July 13	do	225	2,100	2.50	6.58	5,230
August 13	do	207	1,346	1.83	3.24	2,469

[a] Stream full of logs; probably log jam.

[b] Mean velocity=95 per cent of surface velocity.

Mean daily gage height, in feet, of Menominee River near Iron Mountain, Mich., September 4, 1902, to December 31, 1905.

Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	Dec.
1902.					1902.				
1		1.67	2.52	1.60	17	1.40	1.65	6.45	2.55
2		1.53	2.80	2.22	18	1.45	1.92	5.65	2.70
3		1.55	2.95	2.80	19	1.35	1.60	5.35	2.63
4	1.90	1.45	2.72	2.25	20	1.35	1.65	5.00	2.75
5	1.60	1.55	2.85	1.85	21	1.20	1.57	4.47	2.75
6	2.00	1.58	2.95	1.95	22	1.45	1.65	4.45	2.57
7	2.25	1.60	2.50	2.25	23	1.52	1.67	3.90	2.40
8	2.35	1.67	2.60	2.70	24	1.48	2.42	3.92	2.32
9	2.05	1.77	2.50	3.45	25	1.47	2.80	3.45	2.35
10	1.92	1.30	2.40	3.35	26	1.40	3.22	3.30	2.20
11	1.87	1.50	2.45	3.60	27	1.40	2.95	3.00	2.10
12	1.95	1.55	3.27	3.35	28	1.35	3.57	2.62	2.00
13	1.65	2.85	4.85	3.05	29	1.38	3.07	2.55	2.15
14	1.53	2.95	6.07	2.90	30	1.55	2.83	2.62	2.20
15	1.45	2.47	6.88	2.85	31		2.75		2.10
16	1.40	1.82	6.57	2.90					

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1903.												
1	2.55	2.35	2.38	4.68	7.95	9.30	3.70	6.25	4.45	4.30	3.80	3.60
2	2.52	2.30	2.38	5.15	7.85	8.05	4.80	6.20	4.05	4.40	3.80	3.65
3	2.42	2.20	2.42	5.65	9.55	6.30	6.50	4.55	3.70	5.20	3.75	3.55
4	2.48	2.15	2.40	6.35	8.80	7.60	3.85	5.60	3.50	6.60	4.10	3.55
5	2.50	2.15	2.35	2.25	9.45	7.05	3.50	6.60	3.65	7.70	4.00	3.70
6	2.30	2.28	2.48	4.75	9.48	6.50	7.40	8.00	4.00	7.50	3.80	3.60
7	2.25	2.25	2.55	8.30	9.72	3.40	6.30	9.00	4.65	7.65	3.50	3.40
8	2.40	2.22	2.68	5.50	9.60	4.85	5.95	8.90	5.70	7.55	3.65	3.35
9	2.35	2.20	2.72	5.50	9.32	4.85	5.45	7.20	6.65	7.10	3.50	3.35
10	2.30	2.28	2.72	6.05	7.90	4.45	5.25	6.70	6.90	6.85	3.40	3.05
11	2.35	2.40	2.75	6.25	8.98	3.90	5.20	6.75	5.80	6.70	4.10	2.90
12	2.30	2.28	3.00	7.25	8.10	3.50	6.00	6.60	5.50	6.50	4.95	2.60
13	2.20	2.22	3.32	7.15	9.90	4.40	4.65	6.50	7.60	6.25	3.50	2.50
14	2.10	2.25	3.55	6.70	9.45	6.75	4.60	5.40	8.10	5.75	3.20	2.40
15	2.18	2.20	3.50	7.45	9.18	4.50	4.00	5.60	9.00	5.50	3.25	2.45
16	2.22	2.25	3.48	7.52	8.65	4.45	3.40	5.60	10.50	5.40	3.55	2.40
17	2.25	2.22	3.55	7.55	7.60	4.55	3.05	3.70	11.20	4.85	3.25	2.40
18	2.25	2.18	4.25	7.80	6.22	4.80	2.75	4.05	10.40	4.90	2.85	2.35
19	2.32	2.20	6.25	8.30	7.55	3.75	2.85	4.25	9.45	4.90	2.65	2.65
20	2.25	2.18	8.38	7.45	8.72	4.80	2.40	4.05	8.70	4.90	2.85	2.35
21	2.10	2.10	8.85	7.58	9.05	2.30	3.10	3.75	8.00	5.20	2.50	2.30
22	2.20	2.00	7.50	7.05	7.40	3.10	4.20	3.70	6.85	5.30	3.25	2.25
23	2.22	1.95	6.20	6.90	9.40	2.70	3.15	3.75	6.95	4.35	3.00	2.35
24	2.15	2.20	5.95	7.65	6.80	3.10	3.10	3.75	6.35	4.20	3.10	2.30
25	2.12	2.25	5.80	7.50	7.80	2.80	3.25	3.35	5.90	4.05	2.90	2.35
26	2.25	2.32	6.15	7.75	7.15	2.00	4.80	4.05	4.45	3.80	3.00	2.65
27	2.35	2.45	5.42	7.00	8.45	3.80	5.30	4.65	5.50	3.90	2.85	3.15
28	2.25	2.38	5.50	6.45	10.40	2.70	5.70	3.85	4.80	3.85	3.00	3.25
29	2.35	.....	5.15	6.82	11.85	2.45	6.85	3.90	4.40	3.80	3.10	3.10
30	2.35	.....	4.65	7.45	10.10	2.00	8.20	4.00	4.00	3.75	3.60	3.05
31	2.20	.....	4.30	.....	10.75	.....	7.10	4.55	.....	3.70	.....	3.15

Mean daily gage height, in feet, of Menominee River near Iron Mountain, Mich., September 4, 1902, to December 31 1905—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.												
1	.....	4.30	4.75	4.65	7.90	8.45	4.60	2.35	1.80	3.05	3.10	2.42
2	.....	4.25	4.70	4.55	7.95	6.95	2.35	3.30	3.15	2.75	3.65	2.39
3	3.20	4.30	4.55	4.35	8.70	5.65	2.20	2.90	3.70	2.65	4.10	2.22
4	2.90	4.50	4.10	4.60	9.70	6.30	2.90	3.00	4.95	2.45	3.75	2.25
5	2.70	4.30	3.90	5.10	8.15	9.60	2.80	1.30	4.30	2.75	3.25	2.55
6	2.75	4.25	4.50	4.85	9.70	7.30	3.70	2.70	4.00	2.85	3.50	2.50
7	2.75	4.20	4.90	4.70	8.50	8.80	3.60	1.30	4.10	2.55	3.80	2.30
8	3.20	4.20	4.80	4.65	10.40	7.50	3.60	1.20	4.10	2.90	4.85	2.92
9	3.60	4.25	4.70	6.05	11.95	8.55	4.20	1.45	3.70	3.80	4.10	2.95
10	3.50	4.00	3.95	6.20	(a)	8.50	3.30	3.20	3.15	6.70	3.10	2.97
11	3.45	3.90	3.50	4.10	11.80	7.50	4.10	3.80	2.90	7.60	3.20	2.75
12	3.20	3.95	3.00	3.80	11.10	6.70	4.20	4.40	3.10	8.25	3.20	2.50
13	3.10	3.90	3.15	3.65	10.70	6.70	1.80	4.00	2.55	7.80	3.25	2.32
14	3.40	3.85	3.30	3.70	10.55	5.90	4.30	1.90	2.85	7.35	3.05	2.27
15	4.25	3.95	3.25	3.75	9.65	5.40	3.75	2.05	3.50	6.40	2.95	2.32
16	4.30	3.80	3.00	4.10	9.05	4.95	4.30	3.70	3.40	5.90	3.05	2.32
17	4.30	3.75	3.05	3.95	8.10	4.60	1.65	3.60	2.80	5.55	2.80	2.47
18	4.35	3.75	3.35	4.25	8.15	4.50	3.25	4.00	3.15	5.30	3.85	2.50
19	4.35	3.70	3.45	4.40	8.15	3.70	3.05	3.10	2.60	5.20	3.15	2.47
20	4.40	3.90	3.15	4.30	6.25	3.50	2.50	3.15	2.70	5.00	2.92	2.27
21	4.15	3.75	3.15	4.35	4.90	3.50	4.30	2.40	2.95	5.00	2.90	2.22
22	4.10	3.60	3.40	4.40	6.15	4.40	2.70	3.65	2.30	5.05	2.67	2.42
23	4.25	3.60	3.45	5.45	6.10	3.70	2.30	3.45	2.55	5.05	2.77	2.37
24	4.25	3.55	3.75	6.05	7.05	3.70	1.30	3.90	3.80	5.15	2.85	2.40
25	4.20	3.65	4.55	7.35	8.25	5.45	2.75	3.90	3.90	5.05	2.75	.....
26	4.20	3.55	4.60	7.25	9.60	7.20	1.40	3.40	3.95	5.15	2.42	2.47
27	4.25	3.75	4.35	7.45	(a)	6.75	2.70	2.70	4.15	5.05	1.92	2.32
28	4.20	4.55	4.40	8.35	10.90	5.60	1.50	2.30	4.00	4.85	1.75	2.20
29	4.50	4.90	4.30	7.75	10.00	6.70	3.10	1.90	3.50	4.35	2.00	(b)
30	4.45	.....	4.55	7.40	8.70	6.70	1.45	2.05	3.37	4.30	2.07	.....
31	4.35	.....	4.60	.....	8.00	.....	1.30	1.95	.....	3.90	.....	2.60
1905.												
1	2.60	.....	2.35	7.40	8.60	3.60	5.50	4.20	2.80	2.82	3.30	1.80
2	2.58	.....	2.38	6.80	8.40	5.60	8.60	3.70	3.90	2.80	3.30	1.75
3	.....	.....	2.45	6.70	8.50	2.40	6.40	3.40	7.20	2.50	3.20	2.25
4	.....	.....	.....	7.00	9.10	2.40	7.10	3.50	8.00	2.42	3.00	2.30
5	2.35	.....	.....	7.90	9.20	3.50	8.00	3.40	7.80	2.42	3.00	2.25
6	2.60	2.70	.....	8.00	9.20	6.30	8.00	3.45	7.00	2.35	3.00	2.65
7	2.60	.....	.....	7.45	9.30	6.90	7.60	3.30	6.30	2.40	2.95	3.30
8	2.80	.....	2.60	6.80	9.20	7.30	7.60	3.25	5.30	2.42	2.88	3.15
9	2.82	.....	2.62	6.80	9.80	6.30	5.80	3.40	4.60	2.40	2.92	3.20
10	.....	.....	2.60	6.60	9.60	7.10	4.20	3.30	4.40	2.35	3.00	3.20
11	.....	.....	.....	7.00	9.10	5.20	5.20	3.40	4.10	2.40	3.00	3.30
12	.....	.....	.....	7.30	9.00	5.80	4.90	3.20	3.70	2.45	3.00	3.20
13	.....	2.40	.....	7.40	9.10	5.70	5.40	3.20	3.35	2.50	2.90	3.45
14	.....	.....	.....	7.40	8.30	5.70	5.20	3.30	3.00	2.55	2.98	3.30
15	.....	.....	2.38	6.70	7.40	5.80	5.60	3.30	2.95	2.80	3.10	3.25
16	3.20	.....	2.30	6.40	8.60	6.40	4.30	2.80	3.60	2.90	3.15	3.40
17	.....	.....	2.22	6.10	9.70	7.30	4.40	2.50	4.30	2.82	3.05	3.30
18	2.90	2.55	2.25	6.20	10.10	7.20	6.10	2.65	4.40	2.98	2.90	3.25
19	2.92	.....	2.35	5.80	10.20	10.20	3.90	2.50	4.80	3.10	2.88	3.00

a Gage under water.

b River frozen.

Mean daily gage height, in feet, of Menominee River near Iron Mountain, Mich., September 4, 1903, to December 31, 1905—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905												
20	2.95	.....	2.50	5.80	9.30	9.30	3.40	2.70	4.90	3.30	2.90	2.95
21	2.78	2.35	2.40	5.70	10.20	6.70	2.20	2.72	4.80	3.50	3.05	2.85
22	2.75	.....	2.45	6.00	7.40	8.40	2.05	2.25	4.40	3.50	3.05	2.70
23	2.50	.....	2.50	6.20	7.40	6.50	2.95	2.00	3.80	3.50	3.10	2.60
24	.....	.....	2.65	6.00	7.40	6.50	3.90	2.22	3.50	3.50	3.05	2.60
25	.....	2.35	2.98	5.80	6.00	5.80	3.70	2.28	3.45	3.55	3.15	2.62
26	.....	2.40	3.40	6.40	5.20	5.60	3.70	2.20	3.15	3.50	3.20	2.65
27	.....	2.40	3.80	6.80	7.60	7.80	3.40	2.28	2.95	3.40	3.05	2.70
28	.....	2.45	4.60	7.60	5.60	7.60	3.95	2.10	3.05	3.20	2.90	2.55
29	3.00	.....	6.00	8.00	4.80	8.00	4.60	2.12	2.85	3.20	2.50	2.40
30	.....	.....	7.00	8.60	5.80	8.90	4.70	2.07	2.80	3.20	1.80	2.40
31	.....	.....	7.40	.....	3.40	.....	4.60	2.00	.....	3.30	.....	2.48

Rating table for Menominee River near Iron Mountain, Mich., September 4, 1902, to December 31, 1905.

Gage height.	Discharge	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
1.2	1,032	2.8	2,080	4.4	3,242	6.8	5,230
1.3	1,094	2.9	2,150	4.5	3,319	7.0	5,420
1.4	1,156	3.0	2,220	4.6	3,396	7.2	5,615
1.5	1,219	3.1	2,290	4.7	3,474	7.4	5,815
1.6	1,282	3.2	2,361	4.8	3,552	7.6	6,025
1.7	1,346	3.3	2,432	4.9	3,630	7.8	6,235
1.8	1,410	3.4	2,503	5.0	3,708	8.0	6,450
1.9	1,475	3.5	2,575	5.2	3,865	8.5	7,020
2.0	1,540	3.6	2,647	5.4	4,023	9.0	7,630
2.1	1,606	3.7	2,719	5.6	4,183	9.5	8,280
2.2	1,672	3.8	2,792	5.8	4,345	10.0	8,970
2.3	1,739	3.9	2,866	6.0	4,510	10.5	9,670
2.4	1,806	4.0	2,940	6.2	4,680	11.0	10,370
2.5	1,874	4.1	3,015	6.4	4,860	11.5	11,070
2.6	1,942	4.2	3,090	6.6	5,040	12.0	11,770
2.7	2,011	4.3	3,166				

Estimated monthly discharge of Menominee River near Iron Mountain, Mich., September, 1902, to December 31, 1905.

[Drainage area, 2,415 square miles.]

Date.	Discharge.			Run-off.	
	Maximum.	Minimum.	Mean.	Per square mile.	Depth.
190 .	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Inches.*
September (4-30)	1,772	1,032	1,295	0.536	0.538
October	2,625	1,094	1,596	.661	.762
November	5,306	1,806	2,829	1.17	1.30
December	2,647	1,282	1,909	.790	.911
1903.					
April	6,780	1,705	5,175	2.39	2.14
May	11,560	4,698	7,496	3.57	3.10
June	8,020	1,540	3,417	1.57	1.41
July	6,670	1,806	3,553	1.70	1.47
August	7,630	2,467	4,049	1.94	1.68
September	10,650	2,575	5,091	2.35	2.11
October	6,130	2,719	4,057	1.94	1.68
November	3,669	1,874	2,505	1.16	1.04
December	2,719	1,705	2,150	1.03	.890
1904.[a]					
April	8,150	2,683	3,995	1.84	1.65
May	11,770	3,630	7,879	3.76	3.26
June	8,410	2,575	4,791	3.21	1.98
July	3,396	1,094	2,196	1.05	.909
August	3,242	1,032	2,125	1.01	.880
September	3,669	1,410	2,488	1.15	1.03
October	6,725	1,840	3,650	1.74	1.51
November	3,591	1,378	2,293	1.06	.949
December	2,199	1,672	1,838	.877	.761
1905.[a]					
April	7,140	4,265	5,282	2.19	2.44
May	9,250	2,503	6,810	2.82	3.25
June	9,250	1,806	5,011	2.07	2.31
July	7,140	1,573	3,850	1.59	1.83
August	3,090	1,540	2,130	.882	1.02
September	6,450	2,080	3,284	1.36	1.52
October	2,611	1,772	2,163	.896	1.03
November	2,432	1,410	2,204	.913	1.02
December	2,539	1,378	2,085	.863	.995

[a] Ice conditions January, February, and March. No estimate made.

The following table of drainage areas of Menominee River at various points is compiled from Water-Supply and Irrigation Paper No. 83:

Menominee River drainage areas.

	Square miles.
Brule River above Iron River	170.0
Iron River above mouth	94.7
Brule River, including Iron River	264.7
Brule River above Paint River	305.0
Paint River at mouth	738.5
Brule River at junction with Michigamme River	1,044.0

	Square miles.
Michigamme River at mouth	723.7
Menominee River at junction of Brule and Michigamme rivers	1,767.7
Menominee River above junction with Pine River	1,833.0
Pine River	586.0
Menominee River, including Pine River	2,419.0
Menominee River above Sturgeon River	2,538.0
Sturgeon River at mouth	396.0
Menominee River, including Sturgeon River	2,934.0
Menominee River above junction with Pemebonwon River	2,993.0
Peme Bon Won River	163.0
Menominee River, including Pemebonwon River	3,156.0
Menominee River above junction with Pike River	3,274.0
Pike River	292.0
Menominee River, including Pike River	3,566.0
Menominee River above Little Cedar River	3,792.0
Little Cedar River	149.0
Menominee River, including Little Cedar River	3,941.0
Menominee River at mouth	4,113.0

WATER POWERS.

GENERAL CONDITIONS.

Principally because of the opening up of the many rich and valuable iron mines of this region, and the resulting extensive railroad building, the valley of Menominee River has had a rapid development. The following railroads at present have extensions in this territory: Chicago, Milwaukee and St. Paul; Chicago and Northwestern; Minneapolis, St. Paul and Sault Ste. Marie; and Wisconsin and Michigan. All of them cross the Menominee one or more times, and several are near enough to run short spurs to the important water-power sites. The developed water power is at present used for the most part in mining and for the operation of lumber, paper, and pulp mills.

Menominee River varies in width from 200 to 600 or 700 feet far up toward the headwaters. For the first 7 miles from the junction of the Brule and Michigamme there are no heavy rapids, but, in the language of the lumberman, there is "strong water" all the way and probably many good water-power sites.

BAD WATER RAPIDS.

The first notable rapids, known as the Bad Water rapids, occur 7 miles below the head of the river, in sec. 27, T. 40 N., R. 19 E., at a point where the river, 100 feet wide, descends 5 feet over a ledge of rock. While definite information is lacking, it is likely that a dam could be built here, giving a head of 10 feet.

TWIN FALLS.

About 3½ miles below Bad Water rapids, in sec. 2, T. 39 N., R. 19 E., are the Twin Falls, about one-half mile apart. The vertical fall in each case is 12 feet, but the adjacent rapids are sufficient to increase the total descent to 28 feet.

PINE RIVER RAPIDS.

For 6 miles below the foot of Twin Falls the total descent of the river is but 20 feet, and the only rapids worthy of note are those extending for about five-eighths of a mile on both sides of the mouth of Pine River. Here an island divides the river into two channels with rocky bed. The descent of the rapids at this point is said to be 6 feet, but as the banks are high a dam could develop more than this. Pine River increases the drainage area by 586 square miles.

HORSE RACE RAPIDS.

The most important rapids between Twin Falls and Big Quinnesec Falls, called the Horse Race, are found in sec. 7, T. 38 N., R. 20 E., both above and below the Chicago, Milwaukee and St. Paul Railroad bridge. These rapids consist of two pitches, the upper of about 20 and the lower of 8 feet descent, separated by about 2,000 feet of less swift water. As the banks are high and the river narrow, it seems likely that a dam could be economically constructed here to develop about 40 feet of head. This site is only 3 miles from Iron Mountain, Mich.

BIG QUINNESEC FALLS.

A little over 7 miles below the mouth of Pine River, and 4 miles from Quinnesec, are the Big (Upper) Quinnesec Falls. These are located in sec. 6, T. 38 N., R. 20 E.

At Upper Quinnesec Falls the river narrows to hardly more than 50 feet wide (map measurement) between rocky banks of igneous origin. Immediately at the foot of the falls the river widens out, and about 800 feet below is 700 feet across. On the Wisconsin side the banks are 80 to 100 feet high and on the Michigan side 30 to 40 feet.[a]

Below the falls the river descends only 2 feet to the mile for a distance of about 3 miles. At present only 54 feet of the total head is improved, one-half of the power being used to compress air for the supply of the Chapin Iron Mines at Iron Mountain, 3½ miles distant. The remaining portion is to be harnessed in 1905 and used for operating mines at Norway, 9 miles away. On account of the local conditions it is unlikely that much more than the present head can be economically developed.

LITTLE QUINNESEC FALLS.

Four miles below in sec. 10, T. 38 N., R. 20 E., are the Little (lower) Quinnesec Falls, which, together with the upper falls, described above, form the most important powers on the river. For the greater portion of the distance between the upper and lower Quinnesec Falls there is comparatively quiet water. The greater part of the descent of 24 feet in this distance occurs in the lower 2 miles. Above the upper and below the lower falls the banks are generally high near the river, but between these falls the hills recede from the river an average distance of about one-half mile and are separated from it by a flat and in some places swampy area.

Maj. T. B. Brooks, who reported on the geology of this district, considered that the shore deposits indicated the presence of a lake at a comparatively recent date.

Above Little Quinnesec Falls the river runs southwest, but at the foot of the falls it suddenly turns at right angles and runs southeast, the water surging down an incline of about 45° and then plunging into the comparatively still water of the basin below. The total fall is 62 feet. A short distance above the falls the river is 250 feet wide, but narrows down at the pitch to about 50 feet. The falls are hemmed in by great masses of greenstone and schist rock. Along the Michigan side a steep cliff of greenstone at least 140 feet high forms the bank for a distance of a mile or more. A smaller, but similar, rib of rock forms the Wisconsin bank for about 700 feet.

Formerly Little Quinnesec Falls were partially developed under 25 feet head for wood-pulp grinding; but in 1898 they were redeveloped by the Kimberly & Clark Company for wood-pulp and paper manufacturing. A ledge of rock, which is used for a bridge pier, divides the falls into two channels. The present development gives a net head of 62 feet, equivalent to 8,370 theoretical horsepower. An actual installation of turbines, generating 5,800 horsepower, consumes all the available power.

SAND PORTAGE RAPIDS.

These rapids lie between Little Quinnesec Falls and the mouth of Sturgeon River. They receive this name because the Indians, in making their "carry" around part of them,

[a] Tenth Census, vol. 17.

ed over a large amount of sand. The rapids are scattered along a distance of 6 miles, hich space there is a descent of 60 feet. About half of this amount is concentrated in 1½ miles between the falls and the old cable bridge or ferry below. As the topographic shows very high banks, fairly close together, a head of 25 feet or more may some day leveloped here. The Chicago and Northwestern Railway is distant only 1.5 miles.
etween the above-described dam site and a point 2.5 miles below, the river descends eet. A point due south of Norway, Mich., and on the road leading from that city is ably the best location for the dam to develop this fall, but even here a dam not less 700 feet long would probably be required.
enominee River descends but 6 feet between this point and the mouth of Sturgeon er. This may be considered a part of the Sturgeon Falls power.

STURGEON FALLS.

rom below the mouth of Sturgeon River to a point just above Pemebonwon River, a tance of 10 miles, the drainage area increases from 2,934 square miles to 2,993 square es. In this stretch are Sturgeon Falls, one-half mile below the mouth of Sturgeon er, in sec. 22, T. 38 N., R. 21 E., Wisconsin. These falls have high rock-ledge banks, h two pitches aggregating 13 feet. By backing the water a distance of about 3 miles s head could be increased to 15 feet. At the head of the falls the river narrows to about feet, but at the foot it spreads out into a broad basin. In order to use the power it will bably be necessary to blast out a race in the rocks or build a flume and locate the mill or near the foot of the rapids.
n the next 10 miles the river descends only 17 feet, with a fairly even grade, except for or three small rapids. The largest of these, Nose Peak rapids, is about 1,000 feet g and descends about 4 feet.

PEMENA DAM AND RAPIDS.

logging dam which, together with the adjacent rapids, gives a fall of 14 feet in a dis- ce of a quarter of a mile is located in sec. 24, T. 37 N., R. 21 E. The Minneapolis, St. l and Sault Ste. Marie Railway crosses the river 2½ miles above the dam and passes hin a fraction of a mile from it. The operation of a dam at this point for lumbering poses greatly lessens the amount of available power. At the present rate of progress, ever, this dam will be needed for logging only a few more years. It has been found where in the State that river logging, except for pine, can not compete with railroad sportation.
rom below Pemebonwon River to a point just below Pike River, a distance of 18 miles, drainage area increases from 3,156 square miles to 3,566 square miles. Pemena, Chalk l, and White rapids occur in this distance.
bout a mile above the mouth of Pemebonwon River, in sec. 8, T. 36 N., R. 21 E., the nena rapids begin. They extend for a distance of about 2 miles, with a total descent 0.2 feet.[a] The river bed here is a metamorphic slaty schist, and the location is said e favorable for a dam site. The Wisconsin and Michigan Railway runs parallel to the r at this point and is only 2 miles distant, and the Minneapolis, St. Paul and Sault Ste. ie Railway crosses the river a few miles above.

CHALK HILL RAPIDS.

n the 11 miles between the foot of Pemena rapids and the head of White rapids the river ends 38 feet, the grade being even except for three small rapids of from 3 to 6 feet each. lk Hill rapids, the most important of these three, are located in sec. 6, T .35 N., R. 21 E. y run over a slaty rock at a point said to be suitable for a dam, and if developed in con- tion with other falls about half a mile above would give a total head of 8 feet or more.

This statement is based on an accurate profile of the river, prepared by Mr. T. W. Orbison, C. E., his actual surveys. The statement made in the Tenth Census, vol. 17, p. 61, that the total fall feet, is evidently an error.

WHITE RAPIDS.

Four miles above the mouth of Pike River, in sec. 19, T. 35 N., R. 21 E., are the White rapids. The bed of the river is said to be gravel and bowlders, and the banks are high enough to give a head of 30 feet, thus developing the fall for 3 miles. Even above this limit the river descends 10 feet in 1¼ miles, as will be seen from the profile (p. 51). A head of 30 feet at ordinary low water would develop 5,350 theoretical horsepower.

From below Pike River to a point just above Little Cedar River, a distance of 25 miles, the drainage area increases from 3,566 to 3,792 square miles.

All the rapids thus far described have been over the pre-Cambrian crystalline rocks. In the next 28 miles the river crosses the Cambrian sandstone and "Lower Magnesian" limestone. No falls or rapids worthy of note occur until Grand rapids are reached, immediately above the mouth of Little Cedar River, in sec. 5, T. 33 N., R. 22 E. These rapids are caused by a descent over hard "Trenton" limestone, underlain by softer strata. They have a fall stated at 25 feet in a length of 3 miles, but of this fall only that in the lower 2 miles, amounting to 18 feet, can be cheaply developed. Both the Wisconsin and Michigan and the Chicago, Milwaukee and St. Paul railways pass within 2 or 3 miles of this site.

From below the mouth of Little Cedar River to the mouth of the Menominee, 23 miles, the drainage increases from 3,941 to 4,113 square miles.

TWIN ISLAND RAPIDS.

These rapids are situated about 7 miles below the Grand rapids and 16 miles from the mouth of the river. They extend for three-fourths of a mile and are said to descend 10 feet. The two islands lie one below the other, dividing the river into east and west channels. The bed of the river is limestone, the banks are steep, and a dam could be built across each channel to the islands. The total length of such dams is estimated at about 700 feet. A sawmill with a 6-foot head once occupied the east channel.

SCHAPPIES RAPIDS.

Located about 5 miles from the mouth of Menominee River, in T. 31 N. and between Rs. 22 and 23 E., Schappies rapids extend for a distance of about a mile. During the winter of 1897 a survey was made of these rapids by a competent engineer, Mr. C. B. Pride, at a time of extreme low water. He found a discharge of 2,370 second-feet and determined that a head of 18 feet could be economically obtained. This power belongs to the Menominee River Boom Company. The Chicago, Milwaukee and St. Paul Railway is located about 3 miles distant.

MARINETTE DAMS.

The last series of rapids is found at Marinette, Wis., near the mouth of the Menominee. The natural channel probably had about 12 feet descent here, but the Menominee River Boom Company built three dams, one above another, the upper one backing the water to the foot of Schappies rapids. The first of these dams, 850 feet long, located about 3 miles from the mouth of the river, in T. 30 N. and near the line between Rs. 23 and 24 E., develops a head of 7 feet.[a] Power is applied to two paper and pulp mills owned by the Marinette and Menominee Paper Company and also to a flouring mill. No statement of the turbine installation at the paper mills is made, but that at the flouring mill is 95 horsepower.

The third dam from the mouth is located on the west line of sec. 1, T. 30 N., R. 23 E. This dam is 940 feet long and has a head of 18 feet. The middle or second dam is located about a quarter of a mile below the third dam and is 700 feet long, with a head of 7 feet. It is used for boom purposes only. The Marinette and Menominee Paper Company mill

[a] Data regarding the Marinette dams furnished by the owners.

is located just below this dam, but it takes power through a canal from the third dam. Its turbines therefore work under a total head of about 24 feet.

The owners of these three dams state that each could be raised from 5 to 10 feet higher than at present.

TRIBUTARIES OF MENOMINEE RIVER.

The notable Wisconsin tributaries of Menominee River are Brule, Pine, Pemebonwon, and Pike rivers.

Brule River courses in a bed composed mostly of gravel and bowlders of the drift, and for this reason has few vertical falls, one of 10 feet being said to exist at its mouth. It is described as having a series of rapids or "strong water" for its entire length of 42 miles. Its total drainage area, including that of Paint River, is 1,044 square miles.

The following table gives a fairly complete profile of Brule River:

Profile of Brule River, Wisconsin, from its mouth to sec. 23, T. 41 N., R. 14 E.[a]

No.	Station.	Distance— From mouth.	Distance— Between points.	Elevation above sea level.	Descent between points. Total.	Descent between points. Per mile.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
1	Brule, Wis. (C. & N. W. bridge)	7.0	.....	1,260	.....	.....
2	½ mile below section line 22-23, T. 41 N., R. 15 E.	24.0	±17.0	1,411	151	8.8
3	Center of bend E. ¼ stake, sec. 31, T. 41 N., R. 15 E.	29.5	5.4	1,431	20	3.7
4	¼ mile west of east line, sec. 24, T. 41 N., R. 14 E.	31.6	2.1	1,468	37	18.0
5	0.4 mile below dam. Noted below	33.1	1.5	1,490	22	14.6
6	Above dam 800 feet east of ¼ post, sec. 22-23, T. 41 N., R. 14 E.	33.5	.4	1,507	17	42.5
7	¼ mile last of section line 22-23, T. 41 N., R. 14 E.	35.5	2.0	1,520	13	6.5

[a] Authority: No. 1, Chicago and Northwestern Railway; Nos. 2-7, U. S. Geol. Survey.

Pine River, the largest tributary lying wholly in Wisconsin, has a total length of 53 miles and drains an area of 586 square miles.

In the first half mile from its mouth the current is very rapid[b]; in the next 12 or 13 miles the fall is comparatively slight, and in the next 3 miles there are two falls of 8 feet each 1,000 feet apart, half a mile of strong water, succeeded by another fall of 12 feet, then, half a mile above, a fall of 40 feet. Sixty feet above this is a logging dam belonging to the Menominee River Improvement Company.[b]

The length of Pike River is 48 miles.

[b] Tenth Census.

DAMS ON MENOMINEE RIVER AND TRIBUTARIES.

The location and height of dams on Menominee River and tributaries in Wisconsin are shown in the following table:

Dams on Menominee River and tributaries in Wisconsin.

Dam.	Section.	Township.	Range.	Height of dam.
				Feet.
Menominee River:				
1	6	30	24	7
2	1	30	23	7
3	32	31	22	14
Pemena dam	24	37	21	12
Pike River:				
1	8	35	21	9
2	16	35	20	13
North Branch of North Branch Pike River	28	37	18	13
North Branch Pike River:				
1	32	36	20	9
2	20	36	20	13
South Branch Pike River:				
1	19	35	20	13
2	31	36	19	9
3	35	36	18	11
4	29	36	18	10
5	17	36	18	6
Pine River:				
1	30	39	18	9
2	11	39	15	10
3	10	39	14	10
4	36	40	13	9
Brule River:				
1	5	40	17	7
2	19	41	16	8
3	15	42	13	8
Wheeler dam	23	41	14	10

PESHTIGO RIVER.

In length, grade, shape, and size of drainage area Peshtigo River closely resembles its neighbor, the Oconto. It descends an average of nearly 10 feet to the mile, but few of its powers have as yet been developed, because this region is very thinly populated. The only powers reported are two at Peshtigo. A dam with a 10-foot head, owned by the Peshtigo Lumber Company, supplies the power for a sawmill, which has turbines of 1,390 horsepower installed. A flouring mill of 50 horsepower is also located at Peshtigo.

The next important development is a power known as "High Falls" in sec. 1, T. 32 N., R. 18 E. In a distance of 165 feet the river descends 46 feet. A dam 1,000 feet long would increase this to 55 feet. In a recent report on this power by a competent engineer, it is stated that a dam 200 feet long 1½ miles above this point would create an immense reservoir. Both dam sites are on the pre-Cambrian rock, and the banks are of clay and sand.

A few miles below, in sec. 9, T. 32 N., R. 19 E., are the Grindstone Rapids, with a fall of 25 feet. The banks at this point are said to be high and steep. The Wisconsin Geological Survey map shows a descent of 35 feet in sec. 10, T. 33 N., R. 18 E. A dam at Ellis Junction creates a large pond and furnishes a head of 12 feet, which was formerly used to run a sawmill. It is now proposed to increase this head to 24 feet and to use the power for a new pulp mill.

Between Ellis Junction and the mouth the Chicago, Milwaukee and St. Paul and the Chicago and Northwestern railways are adjacent to the river, which is still being used for lumbering purposes. Besides the above-described dams, logging dams are located in sec. 10, T. 33 N., R. 18 E., and in sec. 22, T. 34 N., R. 18 E., with heads of 10 and 8 feet, respectively. The following table shows the profile of the river:

Profile of Peshtigo River from its mouth to near North Crandon.

Station.	Distance from mouth.	Elevation above sea level.	Authority.
	Miles.	*Feet.*	
Mouth of river	.....	581.3	United States engineers.
Peshtigo	18	594.7	Wisconsin and Michigan Rwy.
Do	+18	619.7	Chicago and Northwestern Rwy.
West of Ellis Junction	48	658.0	Do.
Near North Crandon	140	1,620.0	Minneapolis, St. Paul and Sault Ste. Marie Rwy.

OCONTO RIVER.

GENERAL CONDITIONS.

Oconto River rises in a number of small lakes and swamps in the plateau region, at an elevation of about 1,530 feet above the sea. In its length of 87 miles it descends 945 feet. In the upper 35 miles of its course the river flows over the crystalline rocks, and here is found about two-thirds of its total fall. Upon leaving the crystalline rocks the river flows nearly due south for 20 miles over the Cambrian sandstones. At Underhill it turns abruptly and flows nearly due east, crossing the "Lower Magnesian" and "Trenton" limestones and joining Lake Michigan near Oconto. The profile of the river is shown in the following table:

Profile of Oconto River, Wisconsin, from its mouth to Wabena.[a]

No.	Station.	Distance.		Elevation above sea level.	Descent between points.	
		From mouth.	Between points.		Total	Per mile.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
1	Chicago and Northwestern Railway bridge, Oconto	2	.....	581	.....	.....
2	Chicago, Milwaukee and St. Paul Railway bridge, Oconto	7	5	590	9	1.8
3	Stiles	13	6	614	24	4.0
4	Underhill	33	20	770	156	7.8
5	Surings	44	11	791	21	1.9
6	One mile south of mountain	60	16	916	125	7.8
7	Two miles north of mountain	63	3	941	25	8.3
8	Wabena	87	24	1,526	585	24.3

The most important powers are found in the last 33 miles of its course, in which distance the river descends 190 feet.

WATER POWERS.

STILES.

The first dam above the mouth of the Oconto River is located at Stiles, in sec. 34, T. 28 N. R. 20 E., where a dam 400 feet long, with 11-foot head, furnishes power for saw and pulp mills owned by the Anson Eldred Company. This company has installed turbines of 500

[a] Authority: Nos. 1 and 4-8, Chicago and Northwestern Railway; Nos. 2 and 3, Chicago, Milwaukee and St. Paul Railway.

horsepower. It is reported that by constructing a dike about 450 feet long the head could be increased to 18 feet.

OCONTO FALLS.

The most important concentration of fall on the river, about 100 feet, occurs in the "Lower Magnesian" limestone at Oconto Falls, in sec. 25, T. 28 N., R. 19 E. A dam owned by the Falls Manufacturing Company has a head of 37 feet and supplies power for a large paper and pulp mill. The company has installed turbines rated at 1,370 horsepower, besides 400 steam horsepower. About a quarter of a mile farther up is located a dam of 19-foot head, which furnishes power for a large pulp mill, belonging to the Union Manufacturing Company. Seven turbines rated at 940 horsepower are installed. These run twenty-four hours every day except Sunday. Only half a mile below the Falls Manufacturing Company's dam are some important rapids, where an excellent power is available. It is estimated that a dam 250 feet long would develop a head of nearly 40 feet. This power is owned by E. A. Edmonds, who has a charter for a dam at this point with a head of 27.5 feet. The Chicago and Northwestern railway furnishes excellent shipping facilities at all the Oconto Falls powers described above.

PULCIFER DAM.

The last dam used for power purposes is located in sec. 6, T. 27 N., R. 18 E., and furnishes power for a gristmill. It is also used for logging purposes.

MISCELLANEOUS POWERS

The following table gives the location and extent of the most important developed and undeveloped water powers on the Oconto River:

Water powers on Oconto River.

No.	Location.	Estimated head.[a]	H. P. installed.	Use.
	DEVELOPED POWERS.	*Feet.*		
1	Stiles, sec. 34, T. 28 N., R. 20 E.	11	500	Saw and pulp mill.
2	Oconto Falls, sec. 25, T. 28 N., R. 19 E.	37	1,370	Paper and pulp mill.
3	Oconto Falls, sec. 26, T. 28 N., R. 19 E.	19	940	Pulp mill.
4	Pulcifer, sec. 6, T. 27 N., R. 18 E.	12	45	Flouring mill and driving.
5	Sec. 25, T. 31 N., R. 16 E.	12	.....	Driving only.
6	Sec. 4, T. 31 N., R. 16 E.	10	.....	Do.
7	Sec. 23, T. 32 N., R. 16 E.	10	.....	Do.
8	Sec. 30, T. 33 N., R. 17 E.	12	.....	Do.
9	Sec. 5, T. 33 N., R. 16 E.	10	.....	Do.
10	Sec. 1, T. 33 N., R. 15 E.	10	.....	Do.
11	Sec. 11, T. 32 N., R. 16 E.	10	.....	Do.
12	Sec. 34, T. 33 N., R. 16 E.	10	.....	Do.
13	Sec. 30, T. 33 N., R. 16 E.	10	.....	Do.
14	Sec. 27, T. 33 N., R. 15 E.	12	.....	Do.
15	Sec. 18, T. 31 N., R. 17 E.	10	.....	Do.
16	Sec. 33, T. 32 N., R. 17 E.	10	.....	Do.
17	Sec. 21, T. 32 N., R. 17 E.	10	.....	Do.
18	Sec. 23, T. 30 N., R. 16 E.	10	.....	Do.
19	Sec. 16, T. 30 N., R. 16 E.	6	.....	Do.
	UNDEVELOPED POWERS.			
20	Oconto, sec. 23, T. 28 N., R. 21 E.	12	.....	
21	Oconto Falls, sec. 31, T. 28 N., R. 20 E.	40	.....	
22	Sec. 34, T. 28 N., R. 18 E.	15	.....	
23	Sec. 23, T. 31 N., R. 16 E.	20	.....	

[a] The first four heads are reported by owners; the remainder are estimated by Mr. W. A. Holt, of the Holt Lumber Co., Oconto.

WOLF RIVER SYSTEM.

GENERAL CONDITIONS.

Wolf River rises in a number of lakes about 25 miles south of the Michigan boundary and flows in a general southerly direction, entering upper Fox River at a point about 10 miles west of Lake Winnebago. Though nominally a branch of Fox River, it is in reality the master stream, having over three times the discharge. Wolf River receives all its important tributaries from the west and at points relatively near its mouth. It has been elsewhere noted (p. 64) that there is much evidence that the river formerly ran west and joined Mississippi River through the present Wisconsin River Valley between Portage and Prairie du Chien.

In the upper half of its course Wolf River has formed its bed in the pre-Cambrian crystalline rocks, and in this distance the descent of the river is very rapid. At the Chicago and Northwestern railway crossing, 2 miles west of Lenox, the river has an elevation of 1,562 feet above the sea. In the 80 miles between this point and Shawano the river descends 774 feet, or 9.7 feet per mile. This steep gradient causes many rapids and falls. Lumbering dams have been maintained on the upper river at the following points:[a] Sec. 9, T. 33 N., R. 12 E.; Lilly dam, sec. 34, T. 33 N., R. 13 E.; sec. 10, T. 31 N., R. 14 E.; sec. 25, T. 31 N., R. 14 E., and at several other places lower down. In the 40 miles above Shawano small undeveloped powers of 10 to 15 feet head are of frequent occurrence.

Shawano, the head of navigation on the river, and county seat of Shawano County, has a population of 2,000. A dam is located at this point, with a head of 12 feet. It is used to grind wood pulp. Shawano also marks the point of transition from the pre-Cambrian to the Cambrian sandstone. It is at this point that the river crosses the old coast line of Lake Michigan and enters the region of red clay. Below Shawano the stream is sluggish, its descent being only about 42 feet to Lake Winnebago, a distance of about 80 miles. The banks are low, and in high water the surrounding flats are all covered, the river sometimes expanding at time of heavy freshets to several miles in width. For obvious reasons there can be no water powers in this lower region.

The profile of Wolf River for 160 miles of its course is shown in the following table:

Profile of Wolf River, Wisconsin, from mouth to near Lenox.

Station.	Distance from mouth.	Elevation above sea level.	Authority.
	Miles.	*Feet.*	
Winneconne	.....	746.4	United States Engineers.
New London	33	749.5	Chicago and Northwestern Railway.
Shawano	80	788.0	Do.
Lenox	160	1,562.5	Do.

[a] Wisconsin Geological Survey maps.

RUN-OFF.

The following tables showing gage-height observations and discharge measurements at Winneconne and near Northport, on Wolf River, are from data published by the United States Geological Survey:

Discharge measurements of Wolf River at Winneconne, Wis., in 1903.

Date.	Hydrographer.	Gage height.	Discharge.
		Feet.	*Second-feet.*
January 5 [a]	L. R. Stockman	5.50	904
January 24 [a]	do	5.30	1,436
February 20	do	5.00	1,285
March 24	do	6.60	9,998
April 15	do	6.90	3,808
May 11	do	6.70	3,537
June 20	do	6.40	3,194

[a] River frozen.

Mean daily gage height, in feet, of Wolf River at Winneconne, Wis., January 1 to July 25, 1903.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.
1	5.50	5.30	4.80	7.10	6.60	7.00	6.10
2	5.50	5.30	4.80	7.20	6.65	7.00	6.10
3	5.50	5.30	4.80	7.20	6.70	7.00	6.10
4	5.50	5.20	4.80	7.10	6.65	6.90	6.10
5	5.50	5.20	4.80	7.10	6.60	6.80	6.10
6	5.50	5.20	4.90	7.10	6.65	6.80	6.10
7	5.50	5.20	4.90	7.05	6.70	6.85	6.20
8	5.50	5.20	4.90	6.90	6.70	6.80	6.20
9	5.50	5.20	4.90	6.80	6.70	6.80	6.20
10	5.50	5.10	5.00	6.95	6.70	6.80	6.30
11	5.50	5.10	5.00	7.10	6.80	6.70	6.30
12	5.50	5.10	5.10	7.00	6.80	6.70	6.30
13	5.50	5.10	5.25	7.00	6.80	6.60	6.30
14	5.50	5.10	5.30	6.90	6.80	6.60	6.30
15	5.50	5.00	5.60	6.80	6.80	6.60	6.30
16	5.50	5.00	5.70	6.85	6.80	6.50	6.30
17	5.50	5.00	5.80	6.90	6.80	6.50	6.30
18	5.40	5.00	5.90	6.80	6.80	6.45	6.40
19	5.40	5.00	6.00	6.80	6.80	6.45	6.40
20	5.40	5.00	6.20	6.75	6.80	6.40	6.40
21	5.40	4.90	6.30	6.70	6.80	6.40	6.30
22	5.40	4.90	6.40	6.80	6.80	6.40	6.30
23	5.40	4.90	6.50	6.80	6.80	6.30	6.20
24	5.40	4.90	6.60	6.80	6.85	6.30	6.20
25	5.40	4.90	6.70	6.80	6.90	6.20	6.10
26	5.40	4.80	6.80	6.80	6.90	6.20	.....
27	5.30	4.80	6.90	6.70	7.05	6.10	.....
28	5.30	4.80	6.90	6.70	6.90	6.10	.....
29	5.30	.....	6.90	6.65	7.00	6.10	.....
30	5.30	.....	7.00	6.60	7.00	6.10	.....
31	5.30	.....	7.10	.....	7.00	.....	.....

Discharge measurements of Wolf River near Northport, Wis., in 1905.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Square feet.*	*Feet per second.*	*Feet.*	*Second-feet.*
April 5	F. W. Hanna	182	2,642	2.64	7.03	6,965
May 27	S. K. Clapp	171	2,198	1.8	4.65	3,964
June 17	M. S. Brennan	151	2,553	1.97	6.42	5,032
July 15	do	176	2,300	1.69	5.06	3,885
August 16	do	176	2,053	1.26	3.01	2,594
September 22	F. W. Hanna	172	1,978	1.41	3.6	2,781

Mean daily gage height, in feet, of Wolf River near Northport, Wis., April 6 to December 30, 1905.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	3.40	6.00	3.30	2.00	1.60	1.55	1.30	1.70
2	.....	3.60	5.00	3.00	2.30	2.40	1.40	1.40	1.60
3	.....	3.80	5.00	3.40	2.20	2.60	1.35	1.50	1.40
4	.....	4.00	4.90	3.60	2.10	2.20	1.30	1.60	1.50
5	.....	4.20	4.60	3.80	2.30	3.10	1.15	1.70	1.60
6	6.90	4.40	5.60	3.30	2.20	3.40	1.10	1.95	1.75
7	6.80	4.60	5.40	4.30	2.40	3.60	.90	2.10	1.80
8	6.70	4.80	5.30	4.60	2.90	3.30	.85	2.30	1.90
9	6.60	4.80	5.80	4.60	3.30	3.40	.70	2.50	2.10
10	6.50	5.00	5.80	4.90	4.00	3.60	.65	2.70	2.00
11	6.40	5.00	5.80	5.00	3.50	3.80	.60	2.60	1.90
12	6.30	5.20	5.90	5.20	3.60	3.50	.50	2.40	1.95
13	6.10	5.60	6.10	5.10	3.60	2.80	.35	2.30	1.80
14	6.00	5.80	6.40	5.10	3.00	2.50	.10	2.20	1.60
15	5.80	5.60	6.40	4.90	3.00	2.70	.25	2.10	1.40
16	5.60	5.50	6.60	4.20	3.50	2.90	.40	1.80	1.20
17	5.50	5.30	6.50	4.60	3.50	2.80	.75	1.50	1.20
18	5.20	5.30	6.40	4.30	3.30	3.00	.90	1.40	1.10
19	5.20	5.20	6.40	4.80	3.20	3.40	1.15	1.30	1.00
20	4.90	5.00	6.20	4.60	3.00	.....	1.50	1.20	1.00
21	4.80	4.80	6.00	4.45	2.80	2.90	2.20	1.10	1.00
22	4.80	4.60	5.80	4.20	2.40	2.80	2.60	1.00	1.00
23	4.30	4.60	5.60	4.10	2.50	3.70	2.90	.90	.90
24	4.10	4.80	5.30	4.00	2.30	3.60	3.20	.80	.90
25	4.00	5.00	5.10	3.30	2.00	3.40	3.40	.60	.75
26	3.80	5.00	4.70	3.60	1.80	3.25	3.30	.40	.60
27	3.60	4.60	4.40	2.80	1.60	3.10	3.20	.20	.50
28	3.50	4.30	4.00	2.50	1.40	2.90	3.00	.60	.50
29	3.50	5.40	3.80	2.30	1.20	2.75	2.10	.80	.40
30	3.40	5.60	3.50	2.20	1.10	2.35	2.30	1.90	.40
31	.....	5.80	.....	2.00	1.00	.....	2.00	.....	.....

TRIBUTARIES OF WOLF RIVER.

The lower part of the Wolf River drainage area is more thickly settled than the upper, and as a result the tributaries which occupy this lower portion are rather fully developed. This is especially true of Embarrass, Little Wolf, and Waupaca rivers.

WATER POWERS.

The following table shows the water powers on Wolf River and its tributaries:

Water powers on Wolf River and its tributaries.

Location and stream.	Owner and use.	Head.	H. P.
		Feet.	
Manowa, sec. 15, T. 23 N., R. 13 E., Little Wolf River.	Little Wolf River Lumber Co., grist, lumber, electric light.	10	200
Littlewolf, sec. 34, T. 23 N., R. 13 E., Little Wolf River.	Booth & Smith, grist, lumber, electric light.	9	60
Scandinavia, south branch Little Wolf River	Henry Peterson, feed mill	8	23
Sec. 22, T. 23 N., R. 11 E., south branch of Little Wolf River.	J. I. Wralstatt, feed mill	9	50
Phlox, sec. 26, T. 30 N., R. 12 E., Red River	J. Kaufman, saw and planing mill	14	75
Mount Morris, sec. 16, T. 19 N., R. 11 E., Rattlesnake Creek.	Wm. Kemp, grist mill	12	44
Wittenberg, sec. 10, T. 27 N., R. 11 E., Embarrass River.	Viking Lumber Co., sawmill	12	75
North branch of Embarrass River	N. M. Edwards, sawmill	13	50
Sec. 7, T. 26 N., R. 13 E., Embarrass River	N. M. Edwards, undeveloped	20	.....
Embarrass, sec. 5, T. 25 N., R. 15 E., Embarrass River.	Decker & Beedle, lumber and planing mill.	8	115
Sec. 23, T. 26 N., R. 13 E., middle branch of Embarrass River.	Theo. Boettner, flouring mill	9	200
Sec. 15, T. 27 N., R. 15 E., north branch of Embarrass River.	Selber & Dumke, sawmill	13	192
Sec. 23, T. 28 N., R. 12 E., north branch of Embarrass River.	L. A. Weikel, saw, planing, and feed mill.	16	116
Pilla, sec. 9, T. 26 N., R. 14 E., Embarrass River.	Grosskopt, saw and planing mill	13	60
Sec. 9, T. 27 N., R. 12 E., middle branch of Embarrass River.	Buckstaff Lumber Co., power house burned.	10	.....
Waupaca, sec. 32, T. 22 N., R. 12 E., Crystal River.	Waupaca woolen mills	8	35
Waupaca, sec. 20, T. 22 N., R. 12 E., Waupaca River.	A. G. Nelson, planing and grist mill	6½	65
City of Waupaca, Waupaca River	Electric Light Co	18	200
Do	Undeveloped	15	.....
Sherman, sec. 18, T. 22 N., R. 11 E., Waupaca River.	Brooks & Root, flouring mill	7	100
Weyauwega, sec. 4, T. 21 N., R. 13 E., Waupaca River.	Weed Gunnard, flour, planing, and electric light.	10	480
Waupaca, Waupaca River	C. Gurines, brick manufacture	8	30
Amherst, Spring Creek	N. Howard, feed mill	10	20
Rural, sec. 10, T. 21 N., R. 11 E., Arbor Creek	J. Ashmun, flouring and saw mill	9	96
Gresham, sec. 3, T. 27 N., R. 14 E., Red River	A. G. Schmidt, sawmill	11	100
Sec. 6, T. 27 N., R. 15 E, Red River	Undeveloped	.....	.....
Sec. 19, T. 27 N., R. 14 E., Red River	.....do	.....	.....
Sec. 18, T. 28 N., R. 14 E., Red River	.....do	.....	.....
Sec. 15, T. 26 N., R. 10 E., Little Wolf River	Little Wolf River Lumber Co., logging	7	0
Sec. 7, T. 25 N., R. 11 E., Little Wolf River	.....do	7	0
Sec. 5, T. 24 N., R. 13 E., Little Wolf River	.....do	7	0
Sec. 9, T. 33 N., R. 12 E., Wolf River	Used for logging	.....	.....
Sec. 34, T. 33 N., R. 13 E., Wolf River	.....do	.....	.....
Sec. 10, T. 31 N., R. 14 E., Wolf River	.....do	.....	.....
Sec. 25, T. 31 N., R. 14 E., Wolf River	.....do	.....	.....

WISCONSIN RIVER SYSTEM.

TOPOGRAPHY AND DRAINAGE.

› of its length, its great drainage area, and its central location Wisconsin River is ıtly the main river of the State.

e Flambeau, the headwaters of Wisconsin River are found in an intricate network nd swamps occupying the flat plateau region near the northern boundary. Its ource is found in Lake Vieux Desert, a body of water about 10 square miles on the ating the northern peninsula of Michigan from Wisconsin, at about 1,650 feet level. The general course of the river for the first 300 miles is south. At a point ıge it turns abruptly westward, and in the next 100 miles flows nearly west, joining i River at Prairie du Chien, only 40 miles from the southern boundary of the State. ıinage basin includes 12,280 square miles, with an average width of 50 miles and a about 225 miles. The apportionment of this drainage area among the several s of Wisconsin River is shown in the following table:

Distances and drainage areas of Wisconsin River.

River.[a]	Distance.		Drainage area above station.
	From source.	Between stations.	
	Miles.	*Miles.*	*Sq. miles.*
ove mouth		60	940
›uth	60	0	1,202
	85	25	2,111
	113	28	2,697
mouth		23	3,192
ı	136	0	3,690
	138	2	4,114
, above mouth		20	4,268
, mouth	158	0	4,645
Pleine	166	8	5,005
	184	18	5,300
ove mouth		64	6,448
›uth	248	0	7,394
	259	11	8,172
	292	33	9,095
	407	115	12,280

[a] Station is at mouth of river unless otherwise stated.

e of its long traverse from the extreme northern to the extreme southwestern part ısin the topography of the basin includes nearly every form found in the State. upper Chippewa Valley, the northern half is a densely wooded region of hard and er except where cleared for farming. The woods gradually give way to a semi-gion with a gently undulating surface, but with occasional decided ridges both of glacial origin. A very striking surface feature toward the southern part is found araboo quartzite" ranges, which have an elevation of from 400 to 700 feet above the ng country. These ranges comprise two main ridges from 4 to 6 miles apart, ; nearly east and west in the section of country west of Portage for about 25 miles, ıg and ending abruptly on the west side of the valley, near Portage. The angle of ıt this point seems due to its effort to secure a passage around this rock barrier.

;h a portion of the city of Portage and southward, the river can hardly be said to astern divide. Fox River approaches within 1½ miles of the Wisconsin at this point, w marsh intervening. Even this marsh has a slope of about 3 feet toward Fox At the present time levees at this and other points prevent the Wisconsin at times ater from overflowing into Fox River. These levees for a distance of several miles ıe river to flow along the contour instead of in the direction of maximum slope.

The reasons for this and other peculiarities of its valley are interestingly discussed in Geology of Wisconsin, (vol. 3):

> It is evident that such an uncertain divide as this can not have formed one of the original permanent features of the drainage of the region, but as the disposition of the surface soil is due to glacial action, modified by subsequent erosion and transportation, this may be fairly attributed to such a cause. The rampart of limestone which compels the lower Wisconsin to flow west does not stop south of Portage, but continues east and north, although less prominent, forming an eastern barrier to the flow of the Wolf River. The course of the upper Fox to Lake Winnebago is sluggish, consisting largely of marshes and lake-like expansions. On account of the depression of the divide at Portage, the continuation of the southern barrier northeast, the small slope of the upper Fox, the large trough of the Wisconsin below Portage, which it is unable to occupy, while above the river is more nearly in proportion to its channel of drainage, and finally the evidently modern outlet for the Wolf and the upper Fox through the lower Fox—the conclusion is reasonable, if not inevitable, that at one time the Lake Winnebago system drained southwest into the Mississippi and the Wolf was the true continuation of the Wisconsin above Portage, while the present upper Wisconsin was merely a tributary of the main stream.

LAKE ELEVATIONS AND RESERVOIR SITES.

Attention has elsewhere been called (p. 15) to the opportunity of increasing the low-water flow of the northern rivers by the construction of dams near the headwaters for use as reservoirs. The opportunity for such a system on Wisconsin River is especially good, because the ownership of the lands to be flooded is in the hands of a comparatively few corporations and a beginning has already been made. For example, a well-built dam at the foot of the Tomahawk chain of lakes, which impounds water covering many square miles of reservoir, has been used for several years to regulate the stage of the river for the mills below the mouth of the Tomahawk. In scores of cases the dams are already constructed for logging purposes and need only to be kept in repair to be of service for power regulation when they are no longer needed for their original purpose, as will soon be the case.

It has been proposed to build or maintain dams at the following points: Lake Vieux Desert, sec. 17, T. 42 N., R. 11 E.: Twin Lakes, sec. 19, T. 41 N., R. 11 E.; Eagle Lakes, sec. 31, T. 40 N., R. 10 E.; Sugarcamp Lakes, sec. 17, T. 39 N., R. 9 E.; Buckataban Lakes, sec. 24, T. 41 N., R. 9 E.; Little St. Germain Lake, sec. 2, T. 39 N., R. 8 E.; Big St. Germain Lake, sec. 18, T. 39 N., R. 8 E.

At many if not most of the larger lakes near the headwaters, logging companies have long maintained dams, which some day will serve the double purpose of reservoirs and sources of power. A list of some of these lakes, together with their elevation above the sea, as determined by United States engineers, is given in the following table:

Lakes at headwaters tributary to Wisconsin River.

Name of lake.	At headwaters of—	Elevation above sea level.
		Feet.
Eagle	Eagle River	1,582.0
Catfish	do	1,583.0
Cranberry	do	1,583.5
Long	do	1,592.2
Planting Ground	do	1,592.2
Fish	do	1,592.2
Medicine	do	1,592.2
Stone	do	1,592.2
Dog	do	1,592.2
Big	do	1,592.2
Pelican	Pelican River	1,590.0
Tomahawk	Tomahawk River	1,562.2
Island	do	1,560.4
Keawasogan	do	1,560.4
Mud	do	1,553.4
Squirrel	do	1,542.9

The following table *a* gives dimensions and other data of eight reservoir sites surveyed by nited States engineers as an aid to navigation on Mississippi River:

Proposed United States Government reservoirs on Wisconsin River.

Name.	Location.			Elevation of low water at dam site.	Maximum dimensions.				Reservoir.		Area of watershed.
					Dam.		Dike.				
	Section.	Township.	Range.		Length.	Height.	Length.	Height.	Area.	Capacity.	
				Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Sq.mi.*	*Cubic feet.*	*Sq. mi.*
elican	6	36 N.	9 E.	1,520.83	800	28	3,625	15	13.45	5,153,180,527	301.0
ugarcamp	17	39 N.	9 E.	1,562.00	235	12.5	260	4	5.00	1,356,284,160	60.0
tter rapids	36	40 N.	9 E.	1,578.07	1,300	22	700	5	30.74	7,389,727,488	447.0
omahawk	7	39 N.	6 E.	1,554.67	190	12	.....	.....	13.46	2,226,113,036	101.5
quirrel	1	38 N.	5 E.	1,521.78	315	17	.....	.....	5.30	1,338,163,200	56.0
tice	9	35 N.	6 E.	.....	1,100	14	.....	.....	6.00	1,043,516,880	396.0
ieux Desert	17	42 N.	11 E.	.....	.....	.....	.....	.....	7.00	400,000,000	19.0
win Lakes	19	41 N.	11 E.	.....	.....	.....	.....	.....	6.50	650,000,000	30.0
									87.45	19,556,985,291	1,410.5

Subsequent to this report two of these dams, at Rhinelander (Pelican) and Tomahawk, ave been constructed by private enterprise for power purposes; several others have been onstructed with reduced heads. It will be noted that the proposed Government reservoirs have a total area of 87.45 square miles and a drainage area of 1,410½ square miles. It was proposed to fill the reservoirs during the spring freshets and then allow the water to scape at times of low water. The United States engineers estimated that these reservoirs ould maintain a flow of 3,000 second-feet for three months of the year. Such a flow would early double the present low-water flow of the river and its resulting water power. Incientally the use of such reservoirs would to a large extent serve to reduce the dangers of igh floods, both to dams and to overflowed lands. It would, in fact, tend to restore the gimen of the river to that which it possessed before deforesting and cultivation began transform a great primeval forest region into cleared and well-cultivated fields.

PROFILE.

According to the United States engineers, the elevation of Lake Vieux Desert is about 650 feet, while the elevation of the mouth of Wisconsin River at Prairie du Chien is 604 et at low water or 625 feet at high water. This gives a total descent of about 1,046 feet an estimated length of 429 miles, or about 2½ feet per mile. About 634 feet of this fall ccur in the 150 miles between Rhinelander and Nekoosa, an average of 4.23 feet per mile. his descent is concentrated at many places, producing a large number of valuable water owers, many of which have been improved and used by important industries.

The fall in the main tributaries is even greater in many cases than that in the parent stream, and owing to this fact, and also to the absence of lakes and swamps, it is likely that their discharge is subject to great extremes.

a Rept. Chief Eng. U. S. Army, 1880, p. 1655.

A statement in detail of the profile of Wisconsin River is given in the following table:

Profile of Wisconsin River from its mouth to Lake Vieux Desert.[a]

No.	Station.	Distance.		Elevation above sea level.	Descent between points.	
		From mouth.	Between points.		Total.	Per mile.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
1	Mouth of river			604.0		
2	Sauk City	90.0	90.0	746.0	142.0	1.5
3	Merrimac	102.0	12.0	764.0	18.0	1.5
4	Portage	118.0	16.0	790.0	26.0	1.63
5	Kilbourn, railroad bridge	138.0	20.0	814.0	24.0	1.2
6	Sec. 36, T. 15 N., R. 5 E., north line	147.0	9.0	833.0	19.0	2.1
7	Peterwell bridge, opposite Necedah	174.0	27.0	875.3	42.3	1.57
	Nekoosa dam:					
8	Below	208.0	34.0	918.9	43.6	1.28
9	Above			936.6	17.7	
	Port Edwards dam:					
10	Below	212.5	4.5	938.5	1.9	.4
11	Above			955.5	17.0	
	South Centralia dam:					
12	Below	214.0	1.5	957.3	1.8	1.2
13	Above			969.3	12.0	
	Grand Rapids dam:					
14	Below	216.5	2.5	979.8	10.5	4.2
15	Above			1,002.0	22.2	
	Biron dam:					
16	Below	220.5	4.0	1,005.5	3.5	.9
17	Above			1,016.3	10.8	
	Lower paper mill south of Stevens Point:					
18	Below	233.0	12.5	1,032.4	16.1	1.3
19	Above			1,044.0	11.6	
	Upper paper mill south of Stevens Point:					
20	Below	233.5	.5	1,045.5	1.5	3.0
21	Above			1,058.8	13.3	
22	Stevens Point, Wisconsin Central bridge	236.0	2.5	1,063.8	4.0	1.6
23	Sec. 23, T. 24 N., R. 7 E	240.0	4.0	1,075.8	13.0	3.2
24	Knowlton bridge, Chicago, Milwaukee and St. Paul Rwy	257.0	17.0	1,092.2	16.4	.97
25	Sec. 8, T. 26 N., R. 7 E	260.5	3.5	1,097.4	5.2	1.5
26	Sec. 31, T. 27 N., R. 7 E., south line	264.5	4.0	1,104.0	6.6	1.65
27	Mosinee rapids, foot, sec. 29, T. 27 N., R. 7 E., south line	266.0	2.0	1,105.8	1.8	.9
28	Mosinee dam, above	266.5	.5	1,124.6	18.8	37.6
29	Black Creek, mouth of	270.5	4.0	1,125.9	1.3	.3
30	Cedar Creek, mouth of	274.0	3.5	1,130.6	4.7	1.34
31	Eau Claire River, mouth of	279.0	5.0	1,138.6	8.0	1.6
32	Rib River, mouth of	280.5	1.5	1,142.8	4.2	2.8
33	Lower Wausau bridge	283.0	2.5	1,151.0	8.2	3.3
	Wausau dam:					
34	Below	283.5	.5	1,171.0	20.0	40.0
35	Above			1,177.7	6.7	
	Brokaw dam:					
36	Foot	289.0	5.5	1,182.7	5.0	.9
37	Crest			1,194.7	12.0	

[a] Authority: Nos. 1 (low-water elevation) and 53–57, United States engineers; 2 and 3, Major Warren; 4–35, Wisconsin water-power survey by the U. S. G. S. and State authorities; 36–52, levels run by C. B. Pride in 1900 for the Wisconsin River Valley Advancement Association; 56, Chicago and Northwestern Ry.

Wisconsin River from its mouth to Lake Vieux Desert—Continued.

Station.	Distance.		Elevation above sea level.	Descent between points.	
	From mouth.	Between points.		Total.	Per mile.
	Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
outh	298.0	9.0	1,212.7	18.0	2.0
am, foot	304.0	6.0	1,214.7	2.0	.33
am, crest	.....	.....	1,227.7	13.0	.....
m, crest	305.0	1.0	1,233.7	6.0	6.0
ids, foot	314.0	9.0	1,245.7	12.0	1.3
rapids, foot	318.0	4.0	1,272.2	26.5	6.6
above, head	319.5	1.5	1,361.7	89.5	6.0
rapids, foot	321.2	1.7	1,370.7	9.0	5.3
n	326.7	5.5	1,409.7	39.0	7.1
am:					
.....	328.7	2.0	1,412.7	3.0	1.5
.....	.....	.....	1,425.7	13.0	.....
.....	344.7	16.0	1,449.4	23.7	1.48
ids, head	346.7	2.0	1,464.8	15.4	7.7
ot	351.7	5.0	1,477.4	12.6	2.5
lam:					
.....	357.7	6.0	1,523.2	45.8	7.6
.....	.....	.....	1,553.2	30.0	.....
head	392.7	35.0	1,570.7	17.5	.5
N., R. 10 E	402.7	10.0	1,592.7	22.0	2.2
., R. 10 E	416.7	14.0	1,644.0	51.3	3.66
esert	429.0	12.3	1,650.0	+ 6.0	.5

GEOLOGY.

f the Wisconsin River basin above Nekoosa, including over half the entire erlain by pre-Cambrian rocks. North of Merrill this region has been y by drift that the rock rarely outcrops except in the river bed. These ting a barrier to further erosion, cause numerous rapids; in fact, all the ith but a single exception,[a] are found in the pre-Cambrian area. Below Cambrian rocks give way to the softer Cambrian sandstone, the disintegra- made the bed of the river one succession of shifting sandbars, almost with- to its mouth. North of Nekoosa this sandy belt rapidly narrows and, les above, almost entirely disappears, being replaced by the clayey loams North of Tomahawk the clays are replaced again by sandy soils contain- bowlders and glacial drift.[b] In the 60 miles below the city of Tomahawk f Wisconsin River flow mainly through a clayey-loam soil, except for a acent to the main stream, where, as before stated, the sandy soil pre-

RAINFALL AND RUN-OFF.

ates Geological Survey has maintained regular gaging stations at Necedah November, 1902. As the rainfall during 1904 was very close to the average past thirty years, the run-off data for this year are especially valuable.

[a] Kilbourn, in the Cambrian sandstone.
[b] Weidman, Samuel, Wis. Geol. Nat. Hist. Survey, Bull. 11, pl. 1.

Rainfall records for this drainage area are given elsewhere in this report. Th tables give the run-off data:

Discharge measurements of Wisconsin River near Necedah, Wis., in 1902, 1903, 190.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	G. hei
		Feet.	*Square feet.*	*Feet per second.*	*F*
1902.					
December 2	L. R. Stockman				
December 23	do				
1903.					
January 13 [a]	do	280	2,617	1.18	
February 5 [a]	do	284	2,360	1.26	
March 5 [a]	do	284	2,411	1.09	
March 26	Johnson and Stockman		5,405	3.94	1
April 2	L. R. Stockman	220	4,206	2.42	
April 28	do	309	3,860	1.84	
June 12	do	281	3,282	1.79	
July 7	do	316	4,708	4.43	1
August 19	do	302	2,832	2.46	
September 4	do	276	2,463	2.05	
October 12	do	314	3,871	3.23	
1904.					
January 12 [a]	E. Johnson, jr	286	2,031	1.33	
May 11	do	317	4,685	3.65	
May 23	Johnson and Hanna	314	3,717	2.67	
July 16	E. Johnson, jr	294	3,525	1.66	
September 21	do	294	1,823	2.08	
October 14	F. W. Hanna	449	6,216	5.71	1
1905.					
April 4	S. K. Clapp		5,777	5.07	1
May 25	do	317	4,437	3.23	
June 12	M. L. Brennon	437	6,017	4.99	1
August 9	do	314	3,846	2.4	

NOTE.—Width is the actual width of water surface, not including piers. Area of s total area of the measured section, including both moving and still water.

[a] Frozen. [b] Add to this discharge 3,000 second-feet overflow.

Mean daily gage height, in feet, of Wisconsin River near Necedah, Wis., Decembe December 31, 1905.

Day.	1902.	1903.									
	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
1		5.90	5.75	5.75	7.70	6.65	10.55	4.70	4.80	5.20	7.10
2	4.90	5.90	5.70	5.60	7.55	8.30	9.85	4.60	4.95	5.50	6.60
3	4.95	5.80	5.90	5.85	7.35	9.35	8.85	7.70	4.75	5.40	6.80
4	5.10	5.75	5.80	5.80	7.50	9.75	8.15	8.90	4.80	5.30	6.80
5	4.85	5.60	5.75	5.75	7.40	9.95	7.60	10.10	4.85	5.30	7.05
6	4.75	5.70	5.90	5.80	7.25	10.15	7.40	10.00	5.65	5.40	8.30
7	4.70	5.65	5.80	5.90	7.15	10.05	7.15	10.60	6.65	5.60	9.05
8	4.30	5.45	5.70	5.50	7.20	9.70	6.85	10.60	7.75	6.10	8.95
9	4.85	5.60	5.60	5.50	7.10	9.30	6.65	9.70	8.00	6.10	9.15
10	5.25	5.50	5.80	6.25	7.25	8.80	6.55	8.40	7.70	6.80	9.80
11	5.20	5.45	5.75	6.40	7.05	8.25	6.20	7.80	7.50	7.30	9.80
12	5.40	5.50	5.65	7.05	6.90	8.15	6.00	7.50	7.20	7.30	9.35
13	5.25	5.65	5.90	7.65	6.80	8.45	6.15	7.10	6.90	7.20	8.90
14	5.30	5.75	5.80	6.75	6.75	9.05	5.85	6.70	6.70	8.60	8.30

[a] River frozen December 13 to 31.

Mean daily gage height, in feet, of Wisconsin River near Necedah, Wis., December 2, 1902, to December 31, 1905—Continued.

Day.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
15	5.35	5.45	5.75	7.30	6.80	9.80	5.70	6.55	6.70	10.90	7.90	5.35	4.50
16	5.65	5.80	5.65	7.75	6.95	10.10	5.45	6.25	6.40	12.50	7.65	5.25	4.40
17	5.65	5.65	5.65	8.35	7.10	9.90	5.35	6.00	6.20	13.40	7.55	5.35	4.00
18	5.30	5.55	5.55	8.70	7.25	9.35	5.60	6.10	6.40	14.60	7.25	4.90	4.40
19	5.50	5.45	5.75	8.85	7.10	8.70	5.45	5.90	6.10	14.60	6.95	4.90	4.30
20	5.45	5.75	5.70	10.00	6.90	8.30	5.25	6.00	5.70	14.60	7.00	5.00	5.00
21	5.30	5.65	5.70	11.40	6.50	7.95	5.15	5.90	5.90	13.80	6.95	5.10	4.80
22	5.30	5.55	5.65	12.70	6.55	7.90	4.90	5.60	5.40	12.70	6.55	5.05	4.90
23	5.40	5.85	5.55	13.55	6.30	7.75	5.20	5.40	5.10	11.40	6.40	4.95	4.90
24	5.60	5.80	5.70	12.85	6.20	7.45	4.95	5.20	5.10	10.60	6.40	5.20	4.80
25	6.40	5.80	5.65	11.80	6.05	7.35	4.70	5.30	5.40	9.90	6.30	5.20	4.70
26	6.30	5.65	5.65	10.90	6.10	7.60	4.80	5.30	5.20	8.70	6.10	5.05	4.70
27	6.60	5.85	5.70	10.05	6.35	8.00	4.75	5.00	5.30	8.15	6.05	5.00	4.90
28	6.15	5.80	5.85	9.35	6.50	8.70	4.80	5.10	5.30	7.95	5.95	5.15	4.80
29	6.05	5.70	.....	8.95	6.85	9.55	4.70	5.00	5.20	7.65	6.00	5.00	4.90
30	6.20	5.80	.....	8.50	6.60	10.55	4.85	4.90	5.00	7.55	5.80	5.40	4.90
31	6.00	5.80	.....	8.00	.....	11.00	.....	4.80	5.00	.....	5.70	.....	4.90

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.												
1	[a] 6.00	5.10	5.30	[b] 6.60	9.80	11.20	6.30	4.50	4.80	6.60	7.10	4.80
2	5.70	5.20	5.30	6.30	9.20	10.00	6.50	4.70	4.80	6.45	6.90	4.80
3	5.90	5.10	5.30	6.50	8.90	9.10	6.50	4.90	4.80	6.20	6.60	4.80
4	5.60	5.00	5.30	6.90	8.40	8.60	6.30	4.80	4.80	6.10	6.70	(c)
5	6.00	5.20	5.30	6.60	8.00	8.40	6.20	4.70	4.30	7.00	6.50	.....
6	6.00	5.20	5.30	6.80	7.80	9.00	6.30	4.70	5.80	6.00	6.40	.....
7	5.90	5.20	5.30	7.00	7.40	9.90	6.00	4.30	6.30	5.90	6.10	.....
8	6.10	5.00	5.40	7.20	.....	10.50	5.90	4.40	5.90	6.30	6.10	.....
9	6.10	5.20	5.40	7.50	7.40	10.50	6.10	4.80	5.70	6.42	6.60	.....
10	6.00	4.90	5.30	7.90	7.90	9.80	6.30	4.90	5.70	6.70	6.10	5.10
11	5.90	5.10	5.30	8.80	9.50	9.00	6.40	5.30	5.30	8.40	5.90	.....
12	5.10	5.20	5.30	9.80	10.50	8.30	6.80	5.30	5.70	10.10	5.20	.....
13	5.10	5.10	5.30	9.80	10.50	7.80	7.10	5.40	5.30	12.00	5.50	.....
14	5.20	5.20	5.20	9.40	9.90	7.50	7.00	5.30	5.50	13.20	5.50	.....
15	5.20	5.10	5.30	8.70	9.40	7.20	6.50	5.30	5.60	13.00	5.60	.....
16	5.30	5.20	5.20	8.30	9.20	6.80	5.90	5.70	4.90	11.90	5.80	.....
17	5.20	5.20	5.20	7.70	9.00	6.90	5.80	5.00	5.20	10.30	5.50	5.50
18	5.10	5.10	5.20	7.30	8.50	6.70	5.50	5.10	5.30	9.40	5.30	.....
19	5.30	5.10	5.10	7.50	8.00	6.50	5.80	5.00	5.90	9.00	4.80	.....
20	5.00	5.00	5.00	7.50	7.70	6.20	5.50	5.00	5.70	8.40	5.00	.....
21	5.20	5.10	4.90	7.70	7.40	5.90	5.60	5.00	4.80	7.90	5.00	.....
22	5.20	5.10	5.00	7.70	7.20	5.80	5.30	4.70	4.90	8.00	5.30	.....
23	5.20	5.10	5.00	7.50	7.10	6.20	5.00	5.10	4.80	8.50	5.40	.....
24	5.10	5.10	4.80	7.60	7.00	5.70	4.80	4.80	4.70	8.50	5.30	6.00
25	5.00	5.20	5.00	8.00	7.50	6.00	4.50	4.90	4.85	8.30	4.90	.....
26	5.10	5.30	5.00	9.30	8.10	5.70	4.80	4.90	4.80	8.30	5.50	.....
27	5.00	5.40	5.20	10.30	9.40	6.10	4.90	5.00	6.70	7.90	5.10	.....
28	5.10	5.20	5.20	10.90	10.60	5.80	4.80	5.90	7.40	7.60	4.80	.....
29	5.20	5.10	5.20	10.70	11.90	6.10	4.70	4.60	7.40	7.50	5.00	.....
30	5.20	.....	5.50	10.50	12.60	6.00	4.80	5.00	7.00	7.40	5.00	.....
31	5.10	.....	5.80	.....	12.30	.....	4.70	4.70	.....	7.00	.....	6.00

[a] River frozen January 1 to March 31. Ice, average thickness, 10 inches.
[b] Ice conditions April 1 to 12.
[c] River frozen December 4 to 31. Ice 1 foot to 2 feet thick.

Mean daily gage height, in feet, of Wisconsin River near Necedah, Wis., December 2, 1902, to December 31, 1905—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.												
1	(a)	(a)	(a)	13.30	5.95	6.50	7.30	5.50	5.90	6.00	5.00	[b] 5.40
2				13.30	6.10	6.40	7.30	5.30	6.00	5.70	5.50	5.10
3				12.80	6.10	6.40	7.50	5.20	6.20	5.60	5.30	5.10
4		6.00	5.70	12.40	6.00	6.30	7.50	5.20	6.00	5.50	5.40	5.30
5				11.90	6.00	7.70	7.50	5.60	6.10	5.40	5.50	5.60
6				11.60	6.50	8.30	8.10	5.30	6.10	5.40	5.40	5.80
7	6.00			11.80	6.60	11.00	8.60	5.40	6.55	5.40	5.40	6.80
8				11.90	6.70	12.50	9.10	6.60	6.20	5.40	5.40	6.05
9				11.40	6.90	15.00	8.70	6.90	5.70	5.20	5.50	6.30
10				10.60	7.00	17.00	8.30	7.10	5.60	5.30	5.50	8.60
11			6.15	9.90	7.00	16.00	7.60	6.70	5.50	5.00	5.60	8.90
12				9.30	7.50	13.00	7.40	6.50	5.30	4.90	5.50	8.40
13		6.00		9.00	8.30	11.90	7.00	6.70	5.40	4.70	5.50	7.70
14	6.00			8.60	8.50	11.50	6.60	6.40	5.50	4.70	5.50	7.70
15				8.40	8.30	11.20	6.70	6.20	5.50	5.10	5.30	7.60
16				8.00	8.60	10.40	6.50	5.90	5.30	5.10	5.30	7.60
17				7.80	9.30	9.70	6.30	6.00	5.40	5.30	5.10	7.80
18				7.50	9.80	9.50	6.50	5.90	5.50	5.30	5.20	7.30
19				7.10	9.80	9.60	6.30	5.80	6.90	5.60	5.20	7.30
20		6.00		6.70	9.70	11.20	6.30	5.60	7.40	5.60	5.30	7.30
21	6.10		5.00	6.60	9.30	12.40	6.30	5.50	8.20	5.80	5.20	7.20
22			5.00	6.60	8.80	12.30	6.10	5.70	8.40	6.30	4.90	7.10
23			5.00	6.50	8.30	11.00	5.90	5.70	8.40	6.70	4.90	7.10
24			5.30	6.40	8.00	9.80	5.70	5.50	7.80	7.00	4.90	6.80
25		6.00	5.60	6.30	7.70	8.80	5.75	5.70	7.20	6.80	4.80	6.30
26			6.80	6.00	7.20	8.30	6.00	5.90	6.80	6.70	5.10	6.30
27			7.10	6.15	7.10	8.00	5.50	5.30	6.50	6.00	5.10	7.10
28	6.00		8.30	6.00	7.00	7.80	5.10	5.00	6.00	6.40	5.50	6.50
29			9.30	5.95	6.70	7.40	5.30	5.80	5.90	6.20	5.30	6.40
30			10.70	5.90	6.80	7.00	5.10	5.70	6.00	6.20	5.40	6.30
31					6.60		5.30	5.70		6.00		6.10

[a] River frozen over January 1 to March 20. Gage heights are to water surface in a hole in the ice. Thickness of ice, 2 to 2.5 feet.
[b] No ice record for December.

Rating table for Wisconsin River near Necedah, Wis., from March 10 to July 5, 1903.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.6	3,400	5.9	5,680	7.2	9,160	8.8	14,160
4.7	3,540	6.0	5,900	7.3	9,460	9.0	14,800
4.8	3,690	6.1	6,130	7.4	9,760	9.2	15,440
4.9	3,840	6.2	6,370	7.5	10,060	9.4	16,080
5.0	4,000	6.3	6,620	7.6	10,360	9.6	16,720
5.1	4,160	6.4	6,880	7.7	10,670	9.8	17,360
5.2	4,320	6.5	7,150	7.8	10,980	10.0	18,000
5.3	4,490	6.6	7,430	7.9	11,290	10.5	19,600
5.4	4,670	6.7	7,710	8.0	11,600	11.0	21,200
5.5	4,860	6.8	8,000	8.2	12,240	11.5	22,920
5.6	5,060	6.9	8,290	8.4	12,880	12.0	24,670
5.7	5,260	7.0	8,580	8.6	13,520	13.0	28,360
5.8	5,470	7.1	8,870				

[a] Flood in July changed channel.

Rating table for Wisconsin River near Necedah, Wis., from July 6 to December 12, 1903.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet*	*Second-feet.*
4.8	4,200	6.1	6,730	7.4	10,440	9.2	16,480
4.9	4,350	6.2	6,970	7.5	10,760	9.4	17,160
5.0	4,510	6.3	7,220	7.6	11,080	9.6	17,840
5.1	4,680	6.4	7,480	7.7	11,410	9.8	18,520
5.2	4,860	6.5	7,750	7.8	11,740	10.0	19,200
5.3	5,040	6.6	8,030	7.9	12,070	10.5	20,900
5.4	5,230	6.7	8,320	8.0	12,400	11.0	22,600
5.5	5,430	6.8	8,620	8.2	13,080	11.5	24,300
5.6	5,630	6.9	8,920	8.4	13,760	12.0	26,000
5.7	5,840	7.0	9,220	8.6	14,440	12.5	27,700
5.8	6,050	7.1	9,520	8.8	15,120	13.0	29,400
5.9	6,270	7.2	9,820	9.0	15,800	14.0	32,800
6.0	6,500	7.3	10,130				

ting table for Wisconsin River near Necedah, Wis., from January 1 to December 31, 1904.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.0	1,800	5.4	4,880	6.7	8,500	9.0	15,400
4.1	2,000	5.5	5,130	6.8	8,800	9.2	16,000
4.2	2,200	5.6	5,380	6.9	9,100	9.4	16,600
4.3	2,400	5.7	5,640	7.0	9,400	9.6	17,200
4.4	2,600	5.8	5,900	7.2	10,000	9.8	17,800
4.5	2,810	5.9	6,170	7.4	10,600	10.0	18,400
4.6	3,020	6.0	6,440	7.6	11,200	10.5	19,900
4.7	3,240	6.1	6,720	7.8	11,800	11.0	21,400
4.8	3,460	6.2	7,010	8.0	12,400	11.5	23,610
4.9	3,690	6.3	7,300	8.2	13,000	12.0	25,860
5.0	3,930	6.4	7,600	8.4	13,600	12.5	28,230
5.1	4,150	6.5	7,900	8.6	14,200	13.0	30,750
5.2	4,390	6.6	8,200	8.8	14,800	13.5	38,450
5.3	4,630						

Rating table for Wisconsin River near Necedah, Wis., from January 1 to December 31, 1905.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.00	1,800	5.50	5,130	7.00	9,400	9.80	17,800
4.10	2,000	5.60	5,380	7.20	10,000	10.00	18,400
4.20	2,200	5.70	5,640	7.40	10,600	10.50	19,900
4.30	2,400	5.80	5,900	7.60	11,200	11.00	21,400
4.40	2,600	5.90	6,170	7.80	11,800	11.50	23,610
4.50	2,810	6.00	6,440	8.00	12,400	12.00	25,860
4.60	3,020	6.10	6,720	8.20	13,000	12.50	28,230
4.70	3,240	6.20	7,010	8.40	13,600	13.00	30,750
4.80	3,460	6.30	7,300	8.60	14,200	13.50	38,450
4.90	3,690	6.40	7,600	8.80	14,800	14.00	46,200
5.00	3,920	6.50	7,900	9.00	15,400	15.00	61,800
5.10	4,150	6.60	8,200	9.20	16,000	16.00	77,500
5.20	4,390	6.70	8,500	9.40	16,600	17.00	93,300
5.30	4,630	6.80	8,800	9.60	17,200	18.00	109,200
5.40	4,880	6.90	9,100				

The last table is applicable only for open-channel conditions. It is based on 23 discharge measurements made during 1902-1905. It is well defined between gage heights 4.5 feet and 10.5 feet. The table has been extended beyond these limits. From gage height 6.3 feet to 11 feet the rating curve is a tangent, the difference being 300 per tenth. Above 11 feet the bank overflows, which causes the discharge to increase at a greater rate per foot.

Estimated monthly discharge of Wisconsin River near Necedah, Wis., 1903 to 1905.

[Drainage area, 5,800 square miles.]

Date.	Discharge.			Run-off.		Rainfall.[a]
	Maximum.	Minimum.	Mean.	Per square mile.	Depth.	
1903.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Inches.*	*Inches.*
January			[b] 2,600	0.45	0.52	0.36
February			[b] 2,550	.44	.46	.91
March [c]	30,450		11,859	2.04	2.35	2.33
April	10,670	6,015	8,322	1.43	1.60	4.06
May	21,200	7,570	14,492	2.50	2.88	6.23
June	19,760	3,540	6,897	1.19	1.33	1.26
July	21,240	3,400	9,022	1.56	1.80	6.11
August	12,400	4,125	6,648	1.15	1.33	6.26
September	34,840	4,860	15,832	2.73	3.05	5.86
October	18,520	5,840	10,586	1.83	2.11	2.11
November	5,945	4,350	5,007	.86	.96	1.09
December 1-12 [d]	9,520	[e] 5,630	[e] 7,798	[e] 1.34	[e] .60	.88
1904.						
January						.33
February						1.20
March						1.49
April	21,100	7,300	12,830	2.21	2.47	2.01
May	28,720	9,400	15,250	2.63	3.03	6.20
June	22,280	5,640	11,350	1.96	2.19	4.81
July	9,700	2,810	5,926	1.02	1.18	3.28
August	6,170	2,400	3,845	.663	.764	3.21

[a] Rainfall for 1903 is the average of the recorded precipitation at the following stations: Antigo, Koepenick, Stevens Point, Wausau, Amherst, Grand Rapids, and Medford. That for 1904 includes the same stations, except Medford and adding Minocqua and Prentice.
[b] Estimated.
[c] March 1 to 9, inclusive, estimated.
[d] River frozen December 13 to 31.
[e] Twelve-day period.

monthly discharge of Wisconsin River near Necedah, Wis., for 1903 to 1905—Continued.

Date.	Discharge.			Run-off.		Rainfall.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth.	
1904.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Inches.*	*Inches.*
.....	10,600	2,400	5,227	.901	1.01	4.53
.....	33,830	6,170	13,590	2.34	2.70	5.70
.....	9,700	3,460	5,698	.982	1.10	.25
.....	.....	.....	.....	.....	.....	1.86
1905.[a]						
)	.....	20,500	3,920	9,037	1.56	0.58
.....	.....	35,370	6,170	15,790	2.72	3.04
.....	.....	17,800	6,305	11,060	1.91	2.20
.....	.....	93,300	7,300	23,320	4.02	4.48
.....	.....	15,700	4,150	8,711	1.50	1.73
.....	.....	9,700	3,920	6,099	1.05	1.21
.....	.....	13,600	4,630	7,419	1.28	1.43
.....	.....	9,400	3,240	5,748	.991	1.14
.....	.....	5,900	3,460	4,667	.805	.898
.....	.....	14,800	4,150	8,888	1.53	1.76
ear	.....	.....	.....	.....	.....	34.87

[a] No estimate for ice period.

measurements of Wisconsin River at Merrill, Wis., in 1902, 1903, 1904, and 1905.

·.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Square feet.*	*Feet per second.*	*Feet.*	*Second feet.*
7.....	L. R. Stockman.....	.....	.....	.....	7.6	9,015
0.....	.....do.....	.....	.....	.....	3.8	1,394
;.						
.....	.....do.....	310	718	1.91	4.05	1,376
;[a].....	.....do.....	310	669	1.86	3.70	1,250
.....	.....do.....	344	2,639	3.78	8.90	9,995
.....	.....do.....	332	2,232	3.54	6.85	7,893
.....	.....do.....	308	1,269	1.78	4.72	2,258
.....	.....do.....	305	1,424	2.10	5.70	2,993
.....	.....do.....	283	1,115	2.36	5.00	2,638
11.....	E. C. Murphy.....	343	1,759	3.19	6.66	5,614
.....	L. R. Stockman.....	334	1,594	2.61	6.08	4,159
.						
.....	E. Johnson, jr.....	334	2,220	3.71	7.85	8,242
.....	.....do.....	334	2,286	4.19	8.25	9,587
.....	.....do.....	334	1,366	1.98	5.30	3,107
21.....	.....do.....	312	1,210	1.91	5.01	2,312
.....	F. W. Hanna.....	327	2,333	4.42	8.25	10,323
0[a]....	E. Johnson, jr.....	306	1,237	1.85	4.97	2,294
.						
.....	S. K. Clapp.....	334	2,189	3.84	7.8	8,396
.....	.....do.....	324	1,679	2.69	6.25	4,519
.....	M. S. Brennan.....	334	2,334	4.06	8.17	9,478
.....	.....do.....	332	1,596	2.73	6.48	4,357

[a] Partly frozen. [b] Affected by log jam.

Mean daily gage height, in feet, of Wisconsin River at Merrill, Wis., November 16, 1902, to December 31, 1905.

Day.	1902.		1903.											
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	3.65	3.80	3.70	6.75	6.65	.....	7.05	4.30	.....	6.50	5.85	5.10
2	.....	.....	3.70	3.80	3.70	6.70	8.30	.....	7.65	4.30	5.50	5.90	5.60	5.10
3	.....	.....	3.85	3.85	3.80	6.55	.....	.....	7.65	4.90	5.70	6.90	5.30	5.25
4	.....	.....	3.80	3.80	3.75	6.65	.....	.....	8.70	5.60	5.80	7.85	5.30	5.10
5	.....	.....	3.75	3.85	3.80	6.75	.....	.....	8.80	6.55	6.00	8.00	5.30	5.25
6	.....	.....	3.70	3.85	3.70	6.70	.....	.....	8.70	7.45	6.10	7.80	5.75	5.15
7	.....	.....	3.75	3.90	3.80	6.80	.....	.....	8.30	7.35	6.10	8.85	5.30	5.20
8	.....	.....	3.70	3.80	3.75	6.90	.....	.....	8.10	7.25	6.50	8.55	5.10	5.20
9	.....	.....	3.65	3.90	3.75	6.75	.....	.....	7.70	(a)	6.60	8.35	5.20	5.15
10	.....	4.00	3.65	3.85	3.90	6.70	.....	.....	7.60	.....	6.80	8.20	5.10	5.05
11	.....	3.95	3.70	3.55	4.05	6.75	.....	.....	7.50	.....	6.90	7.70	5.30	4.95
12	.....	4.00	3.70	3.85	4.20	6.55	.....	.....	7.30	.....	9.10	7.25	5.25	4.70
13	.....	4.00	3.80	3.75	4.75	6.05	.....	.....	6.30	.....	9.40	7.35	5.25	4.90
14	.....	3.85	3.75	3.70	5.00	6.70	.....	.....	5.50	.....	10.00	7.10	5.25	4.80
15	.....	3.65	3.65	3.75	5.05	6.75	.....	.....	6.00	.....	11.10	7.10	5.05	5.30
16	3.60	3.85	3.50	3.80	5.05	6.80	.....	.....	5.40	.....	11.50	6.75	5.50	4.55
17	3.80	3.85	3.70	3.90	5.50	6.85	.....	.....	5.50	.....	10.80	6.60	5.35	5.00
18	2.50	3.90	3.70	3.75	5.55	6.75	.....	.....	5.40	.....	10.10	6.60	4.65	5.10
19	2.05	3.85	4.20	3.55	7.90	7.10	.....	5.15	5.15	.....	9.40	6.60	4.75	5.10
20	1.90	4.05	4.00	3.70	8.35	7.20	.....	5.20	5.55	.....	8.90	6.35	4.85	5.20
21	1.90	3.80	3.85	3.65	8.30	7.10	.....	5.55	4.65	.....	8.50	6.35	4.75	5.20
22	1.55	3.80	4.00	3.85	8.00	6.80	.....	5.60	4.90	.....	8.10	6.35	4.55	4.80
23	1.05	3.75	4.00	3.45	8.25	6.75	.....	6.00	5.40	.....	7.90	6.40	4.60	4.80
24	.90	3.85	4.00	3.65	7.50	6.80	.....	6.45	5.10	.....	7.70	6.15	4.70	5.10
25	1.05	4.05	4.10	3.70	7.35	7.05	.....	6.40	4.65	.....	7.10	6.05	4.90	5.00
26	.55	3.95	4.05	3.70	7.00	6.10	.....	5.85	5.10	.....	7.20	6.00	5.35	5.20
27	.15	3.90	4.00	3.60	6.65	6.35	.....	5.35	4.10	.....	7.20	5.85	5.25	5.50
28	.05	3.80	3.85	3.65	6.05	6.50	.....	5.35	4.50	.....	7.05	5.75	4.85	5.00
29	.10	3.70	3.95	.....	6.80	6.85	.....	6.30	5.60	.....	5.40	5.85	4.85	5.50
30	.....	3.70	3.90	.....	6.45	6.60	.....	6.75	4.50	.....	6.05	5.95	5.05	5.80
31	.....	3.70	3.85	.....	6.70	.....	.....	.....	4.30	.....	.....	5.60	.....	5.60

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.												
1	5.90	5.65	5.90	5.90	7.55	7.55	6.75	5.15	5.05	6.15	6.70	4.85
2	6.00	5.65	5.95	5.85	7.10	7.25	6.80	5.20	4.90	6.25	6.60	5.20
3	6.05	5.60	5.90	5.90	6.80	7.30	6.60	5.10	5.95	6.70	6.25	4.85
4	6.10	5.55	5.90	5.85	7.05	7.70	6.20	5.00	7.80	5.85	5.90	4.85
5	6.10	5.70	5.90	5.90	7.30	8.05	6.25	5.05	6.90	6.40	5.75	4.75
6	6.00	5.70	5.85	6.40	6.75	8.30	6.20	5.25	6.25	5.90	5.70	4.95
7	5.75	5.60	5.95	6.35	6.75	7.80	6.20	5.20	7.05	5.60	5.55	4.80
8	5.80	5.80	5.85	6.65	7.05	7.85	6.35	6.65	7.00	6.70	5.15	5.15
9	5.50	5.80	5.90	7.20	8.40	7.55	6.70	5.10	6.75	7.75	4.70	5.00
10	5.85	5.75	5.90	7.15	8.20	7.35	6.95	5.20	5.90	10.10	4.55	5.00
11	5.55	5.85	5.90	7.15	7.90	7.00	7.20	5.30	6.15	10.40	4.40	4.65
12	5.70	5.75	5.90	6.75	7.95	7.55	6.55	6.20	6.60	10.15	4.75	4.45
13	5.75	6.10	5.80	6.80	7.70	7.25	5.45	7.15	6.15	9.05	5.90	4.80
14	5.70	5.55	5.80	6.65	7.95	6.50	6.00	5.50	5.95	8.30	6.00	5.05
15	5.55	5.60	5.90	6.35	7.70	6.20	5.75	5.30	5.95	7.55	4.60	5.20

a Chain gage stolen.

ean daily gage height, in feet, of Wineonsin River at Merrill, Wis., November 16, 1902, to December 31, 1905—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.												
.....	5.60	5.65	5.85	5.85	7.90	6.10	5.60	5.70	5.90	7.15	4.50	5.30
.....	5.60	5.95	5.90	6.45	7.40	6.05	5.80	6.65	5.90	6.90	4.55	5.20
.....	5.55	5.90	5.75	6.30	6.55	6.10	6.05	5.90	5.95	6.90	4.55	5.20
.....	5.65	5.90	5.65	6.35	6.75	6.50	4.50	5.75	5.90	6.95	4.75	5.10
.....	5.60	6.15	5.70	6.15	6.75	6.20	4.60	6.40	5.20	6.25	5.05	5.05
.....	5.70	5.85	5.75	6.05	6.85	6.05	5.10	6.10	5.35	6.35	5.10	5.20
.....	5.65	5.95	5.80	6.05	7.05	6.10	5.20	6.20	5.05	6.80	5.25	5.70
.....	5.60	5.90	5.35	6.10	7.05	6.05	5.30	6.15	5.50	6.65	5.10	5.25
.....	5.50	5.90	5.75	7.00	7.05	7.25	4.90	5.85	6.80	6.55	4.95	5.20
.....	5.85	5.90	6.00	8.10	8.10	5.60	4.50	5.80	7.10	7.10	4.75	5.45
.....	5.55	5.90	5.85	8.35	10.10	6.00	4.60	5.70	7.75	7.20	4.95	5.05
.....	5.55	5.90	5.55	8.45	10.60	6.25	5.40	6.00	7.15	6.90	5.45	5.60
.....	5.55	5.90	5.70	8.50	9.80	7.25	5.10	5.50	7.20	6.75	5.15	5.95
.....	5.55	5.95	5.80	8.20	9.05	6.80	5.50	5.90	6.40	6.85	5.15	5.60
.....	5.55	.....	5.70	7.75	8.60	6.30	5.70	6.35	6.10	6.65	4.85	5.50
.....	5.50	.....	5.80	.....	7.95	.....	5.50	5.05	.....	6.25	.....	5.15
1905.												
.....	5.20	5.25	5.35	8.90	5.15	5.80	7.40	5.05	6.10	6.20	6.20	5.20
.....	4.95	5.00	5.35	8.80	5.70	5.70	7.30	5.45	6.20	6.00	6.30	5.70
.....	5.20	4.90	5.20	9.20	6.20	5.90	7.50	5.35	6.15	6.20	5.60	5.60
.....	5.70	5.15	5.40	8.90	6.10	5.50	7.60	5.35	6.70	6.00	5.25	5.80
.....	5.35	5.50	5.25	8.80	6.25	7.60	8.00	5.95	6.70	6.05	5.80	5.40
.....	5.40	5.35	5.35	8.80	6.40	10.40	8.20	6.10	6.25	6.00	5.35	5.25
.....	5.20	5.15	5.55	8.80	6.45	10.00	7.70	6.85	6.00	5.30	5.10	5.55
.....	5.45	5.25	5.15	8.20	7.20	9.00	7.80	6.00	6.25	5.30	5.55	5.55
.....	5.15	5.10	5.20	8.60	6.70	9.00	8.00	6.25	6.10	4.30	5.45	5.35
.....	5.05	5.40	5.65	7.80	6.45	8.40	7.20	6.40	6.30	4.90	5.90	5.75
.....	5.35	5.20	5.45	7.40	6.95	8.50	6.85	6.05	6.15	6.15	5.80	5.70
.....	5.50	4.95	5.05	7.20	7.20	8.40	7.05	5.75	6.30	6.80	5.15	5.55
.....	5.50	5.20	5.45	7.40	6.90	7.80	6.20	6.00	6.65	6.45	5.30	5.60
.....	5.90	5.25	4.70	7.00	7.40	7.80	6.30	6.15	6.40	6.55	5.00	5.60
.....	6.00	5.15	4.70	6.90	7.60	7.60	6.80	5.90	6.05	5.90	5.20	5.35
.....	5.95	5.50	4.95	7.20	7.60	8.10	6.50	6.05	6.40	6.15	5.65	5.70
.....	5.75	5.70	5.05	7.40	7.80	10.40	6.30	5.90	6.60	5.85	5.70	6.15
.....	5.85	5.65	5.25	7.00	7.80	10.60	6.55	6.40	6.45	6.25	5.75	5.50
.....	5.65	5.55	5.25	6.45	7.50	10.60	5.05	6.25	6.90	6.65	5.85	5.60
.....	5.15	5.35	5.25	6.45	7.30	9.60	5.65	6.20	7.35	6.85	5.45	5.65
.....	5.15	4.30	5.50	6.45	7.00	9.20	6.45	5.90	6.70	6.70	5.75	5.75
1.....	5.60	5.20	4.95	6.05	6.75	8.60	6.00	6.80	7.30	6.70	5.75	5.75
1.....	5.80	5.75	4.95	5.95	6.80	8.50	5.50	6.50	6.90	6.80	5.75	5.45
1.....	6.05	5.80	5.35	5.60	6.40	8.00	5.40	4.80	6.80	6.15	5.60	5.55
5.....	6.15	5.60	4.55	5.75	6.45	7.60	5.20	5.55	6.50	6.30	5.70	5.90
6.....	5.85	5.15	5.75	6.20	6.30	6.90	5.10	6.35	6.25	6.70	5.20	6.25
7.....	5.85	5.65	6.05	5.90	6.35	7.60	5.65	6.40	6.55	6.55	4.80	5.90
8.....	5.25	5.35	7.40	5.65	6.35	7.50	5.80	6.25	6.15	6.90	5.15	5.60
9.....	5.10	.....	8.00	5.95	6.25	6.75	5.60	5.75	5.95	6.50	5.65	5.85
0.....	5.05	.....	8.60	5.45	6.25	7.05	5.75	6.00	6.45	5.70	5.50	5.70
1.....	5.15	.....	8.50	.....	6.00	.....	4.30	6.80	.....	5.80	.....	5.40

NOTE.—No ice record at this station.

Rating table for Wisconsin River at highway bridge near Merrill, Wis., from June 17, 1903, to December 31, 1904.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-ft.*	*Feet.*	*Second-ft.*	*Feet.*	*Second-ft.*	*Feet.*	*Second-ft.*
4.5	1,485	5.5	3,225	6.5	5,485	8.0	9,565
4.6	1,645	5.6	3,425	6.6	5,725	8.2	10,225
4.7	1,805	5.7	3,635	6.7	5,975	8.4	10,885
4.8	1,970	5.8	3,855	6.8	6,225	8.6	11,545
4.9	2,140	5.9	4,075	6.9	6,475	8.8	12,205
5.0	2,310	6.0	4,305	7.0	6,725	9.0	12,865
5.1	2,485	6.1	4,535	7.2	7,245	9.5	14,515
5.2	2,665	6.2	4,765	7.4	7,785	10.0	16,165
5.3	2,845	6.3	5,005	7.6	8,345	10.5	17,815
5.4	3,035	6.4	5,245	7.8	8,935	11.0	19,465

Estimated monthly discharge of Wisconsin River at Merrill, Wis., for 1904.

[Drainage area, 2,630 square miles.]

Date.	Discharge.			Run-off.		Rainfall.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth.	
1904.	*Sec. ft.*	*Sec. ft.*	*Sec. ft*	*Sec. ft.*	*Inches.*	*Inches.*
January	4,535	3,225	3,664	1.39	1.60	0.33
February	4,655	3,330	3,749	1.43	1.54	1.20
March	4,305	2,945	3,889	1.48	1.71	1.49
April	11,220	3,970	6,242	2.37	2.64	2.01
May	18,140	5,610	8,935	3.40	3.92	6.20
June	10,560	3,425	6,472	2.46	2.74	4.81
July	7,245	1,485	3,957	1.51	1.74	3.28
August	7,110	2,310	3,766	1.43	1.65	3.21
September	8,935	2,140	5,000	1.90	2.12	4.53
October	17,480	3,425	7,343	2.79	3.22	5.70
November	5,975	1,410	2,800	1.06	1.18	.25
December	4,195	1,490	2,566	.976	1.12	1.86
The year	18,140	1,410	4,865	1.85	25.18	34.87

RAILROADS.

The railway facilities will be discussed in connection with each power, but in general it may be said that they are excellent. The willingness of the railroads to go where there is an assured traffic is seen at Nekoosa. Since the construction of the paper and pulp mill at this point three different railroads have extended their lines to the mill.

The land is being rapidly cleared and made into farms, especially during the past five years. This fact insures the certain and steady extension of the railroads in this region.

WATER POWERS.

In the first 138 miles above its mouth Wisconsin River occupies a wide, sandy valley, entirely devoid of any falls or rapids, and showing a very uniform descent of only 1½ feet per mile.

KILBOURN.

The first water power is found at Kilbourn, where the river flows across the Cambrian sandstone in a narrow, deep gorge known as "The Dell," 100 to 600 feet wide and 40 to 70 feet deep. The drainage area of Wisconsin River at Kilbourn is about 8,200 square miles. According to discharge measurements made by United States engineers, the low-water discharge is 3,000 second-feet. A dam with a crest 3 feet above low water was for many years operated here, under an old charter, the power being used for a flouring mill. This was burned down over thirty years ago and since that time no use has been made of the power.

The Madison Traction Company, of Madison, Wis., has a charter for a 15-foot dam above the ordinary low-water level, with the privilege of 2 feet of flashboards, giving a head of 17 feet or more. It has been proposed to build an electric railroad from Madison northward via Kilbourn, as an extension of the present Madison street railway system, and the plans contemplate using this water power to drive the dynamos.

The river continues to flow in the Cambrian sandstone for the next 70 miles, until Nekoosa is reached. Although the river descends over 105 feet in this distance the fall is so evenly distributed that good water-power sites are lacking. At Nekoosa, however, for the first time, we find the river flowing in the hard pre-Cambrian crystalline rock. In the next 8½ miles above, the river has a descent of 83 feet, nearly all of which is improved by 5 dams. These dams furnish power for 5 large modern paper and pulp mills and will be described in order, beginning below.

NEKOOSA.

A rock crib dam at Nekoosa develops a head of nearly 20 feet. This power is used to operate a modern paper and sulphite mill, one of the largest on the river, owned by the Nekoosa Paper Company. An installation of 37 turbines is reported, developing a total of 4,560 actual horsepower for twenty-four hours per day. The drainage area of the river at this point is about 5,700 square miles.

PORT EDWARDS.

About 4½ miles farther upstream is another fully developed power owned by the John Edwards Manufacturing Company. A head of 18 feet is here available. Turbine wheels, to the number of 28, develop 3,860 actual horsepower, which is used to run a large paper and pulp mill. Two miles farther upstream is the Centralia Pulp and Water Power Company's dam, with an average head of 13 feet. Turbines of 1,460 horsepower are here installed, according to the company's report, all used in the manufacture of paper and pulp.

GRAND RAPIDS.

One of the largest and most complete paper and pulp mills in the entire State, owned by the Consolidated Paper and Power Company, is located on the west side of the river, within the city limits of Grand Rapids. This mill was erected in 1902 and its installation of paper-making machinery has all the recent important improvements. Before this mill was constructed there was a total descent of 30.8 feet between the foot of Biron dam, 4 miles above, and the Grand Rapids bridge. Of this amount the new masonry and concrete dam of the Consolidated Paper and Power Company develops a head of about 25 feet. Turbines of 6,500 horsepower are already installed, flume space being also provided for the development of an additional 1,000 horsepower for future expansion. Prior rights to 500 horsepower developed by this dam are owned by the Grand Rapids Milling Company, which uses it in the manufacture of flour.

The Pioneer Wood and Pulp Company has certain rights to about 600 or 800 horsepower "when the stage of the river will permit," which has meant about ten months each year. This power is used by the company for grinding wood pulp. The Grand Rapids foundry also has rights to about 40 horsepower from the same dam. The milling company

and the foundry both receive their power from the Consolidated Company in consideration for power previously owned by them and displaced by the present dam.

The above-described four paper mills have the advantage of competition in freight rates incident to being served by each of the following railways: The Chicago and Northwestern; Chicago, Milwaukee and St. Paul; Green Bay and Western; and Wisconsin Central.

About 4 miles above Grand Rapids is located the dam of the Grand Rapids Paper and Pulp Company. A head of from 10 to 12 feet, depending on the stage of the water, is reported with turbines already installed of 3,063 horsepower. This company is served by the Green Bay and Western Railroad. In the 13 miles between the crest of the Biron dam and the foot of the next one above, near Stevens Point, Wisconsin River descends 16 feet. The only rapids in this distance is one of 3½ feet called "Crooked Rift," about 4 miles above the Biron dam. The greater part of this fall properly belongs to the Biron power and is largely developed by the splash boards of that dam.

STEVENS POINT.

Owing to the peculiar topography of the river valley between Nekoosa and Stevens Point, whereby the adjacent tributaries flow for long distances parallel to the main river, and to the decided narrowing of the river valley between these points, the discharge of Wisconsin River at Stevens Point does not differ greatly from that at Nekoosa. The drainage area at Stevens Point is about 5,600 square miles.

In the city of Stevens Point and immediately south of it are found three developed powers and one undeveloped. Of the former, the lower two are owned and operated by the Wisconsin River Paper and Pulp Company. One of its dams is located in the NE. ¼ sec. 17, T. 23 N., R. 8 E., just below the mouth of Plover River, and supplies a head of 9 feet. At this point a large island occupies the middle of the river and is made use of in the construction of the dam. The company has installed turbines rated at 1,370 horsepower. One-half mile above this dam, at a point where the river is much narrower, is located the second dam belonging to this company, giving an average head of 16 feet. Here are installed 18 turbines rated at 4,660 horsepower. This power, as well as that derived from the dam below, is used in the manufacture of pulp and paper. Both mills are located on the east or right bank and have good shipping facilities. Above the last-described power and about a mile below the dam next above is an undeveloped power of about 7-foot head belonging to the same company. As the river is wide at this point, a very long dam would be required to develop this power, but its location in the city would make it very valuable.

The third dam is located within the limits of the city of Stevens Point and is owned by the Jackson Milling Company. This dam develops an average head of 7 feet. The owners have installed only 3 turbines, rated at 140 horsepower, which is used to run a flour and feed mill. By building a new dam 1,000 feet below the present one, with a crest of 10 feet, a 12-foot head could easily be obtained without flooding. On account of its location in a growing city of 10,000 people, it would seem that all this power could easily find takers at remunerative rates.

BATTLE ISLAND.

In the 19 miles between the head of the upper dam at Stevens Point and the bridge of the Chicago, Milwaukee and St. Paul Railway near Knowlton, according to railroad levels, the river descends 30 feet. In this distance there is only one opportunity for the development of water power, namely, at Battle Island, in sec. 28, T. 26 N., R. 7 E. From the foot of the rapids at Mosinee to Battle Island, according to a survey, there is a fall of 20 feet. The banks at this point are said to be high, so that a dam could be economically built with a head of 20 feet. The Wisconsin Valley division of the Chicago, Milwaukee

and St. Paul Railway is distant less than a mile from this site, and rock and timber are very abundant and near at hand; in fact, the bed and banks of the river are in rock.

MOSINEE.

An easily developed power, one of the best on the river, is found at Mosinee, in sec. 31, T. 27 N., R. 7 E. It is owned by the Joseph Dessert Lumber Company. About forty years ago a flooding dam with a head of 5 or 6 feet was built here, and it has since been rebuilt several times. The dam was located near the head of the rapids, probably because of the ease of construction due to a large island in the river at this point. Later a sawmill was built on the right bank, thereby securing a head of about 12 feet. At the present time this mill is run by steam power, and no use is made of the water power. An effort is now being made to interest capital to develop this power to its maximum amount for a proposed paper and pulp mill. This will require a new dam. Such a dam could be made to develop a head of 20.7 feet by flooding a small marsh above. The high banks and the bed of the river are in the hard crystalline rock.

ROTHCHILDS.

In the 18 miles between the east quarter stake of sec. 35, T. 29 N., R. 7 E., below the mills at Wausau, and the crest of the Mosinee dam, Wisconsin River descends 28 feet.[a] A considerable portion of this fall is concentrated in rapids in sec. 24, T. 28 N., R. 7 E. at a place called Rothchilds. The right bank is steep, but the left bank is much less so. A dam could be built here which would develop a head of nearly 20 feet but it would need to be long. Rib and Eau Claire rivers, with drainage areas of 500 and 423 square miles, respectively, enter Wisconsin River from opposite sides but a short distance above Rothchilds. This place is 7 miles from Wausau and is reached by the Chicago, Milwaukee and St. Paul Railway. During the year 1903 Wausau capitalists made earnest efforts to acquire the necessary flowage rights for the improvement of this power, but the owners of the land were unwilling to sell at the rates offered and the project was dropped.

WAUSAU.

Only a portion of the valuable water power located in the city of Wausau has been developed. A high granite island, nearly a quarter of a mile long, occupies the middle third of the river at this place, the main dam being built from the head of this island to the right bank, a distance of about 350 feet. The guard lock is located on the opposite channel, at the site of the Scott Street Bridge, and is about 300 feet long.

Near the head of the island is located the McEchroy roller mill. Three turbines, installed under an average head of only 7½ feet, develop 296 actual horsepower, which is ample for this mill as at present equipped.

About 1,000 feet below the guard lock are situated the Alexander Stewart Lumber Company's planing and saw mills, working under heads of 9 and 11 feet, respectively. Four turbines, rated at 200 horsepower, are installed. The planing mill runs ten and the sawmill twenty hours a day. The company also has 350 steam horsepower.

About 1,300 feet below the guard lock is located the plant of the Wausau Paper Mills Company, which takes its power from the old dam, but because of the location so far below has the advantage of the additional fall in the river. This gives an average head of 14 feet. The company has installed 12 turbines, rated at about 3,600 actual horsepower, and in addition has 500 steam horsepower. This mill runs twenty-four hours a day.

During the past year the Wausau Electric Company has acquired rights to two-ninths of the total flow of the stream, and has blasted a new tailrace out of the solid rock for a distance of 300 or 400 feet, thereby increasing the head to 22½ feet. This company has as yet installed only one pair of turbines, rated at 700 horsepower, but intends to double

[a] U. S. Geol. Survey topographic map.

this in two years. The Stewart Lumber Company owns three-ninths and D. L. Plumer four-ninths of the total flow of the river.

Wausau is a city of about 13,000 inhabitants and is the county seat of Marathon County. The Marshfield branch of the Chicago and Northwestern Railway crosses Wisconsin River at this point, and the city is served also by the Chicago, Milwaukee and St. Paul Railway.

BROKAW.

In the 20 miles (by river) between the foot of the lower dam at Merrill and the head of the Wausau dam Wisconsin River descends about 55 feet, 35 feet of this being between Wausau and the mouth of Pine River.[a] The only portion of this fall at present developed is at Brokaw, where a dam with a head of 12 feet furnishes power for a large paper and pulp mill. Twelve turbines, rated at 3,964 horsepower, are installed. Brokaw is about 6 miles above Wausau, in sec. 3, T. 29 N., R. 6 E., and is reached by the Chicago, Milwaukee and St. Paul Railway.

TRAPP RAPIDS.

About 4 miles above Brokaw, near the mouth of Trapp River, are the Trapp rapids.[b] The bed of the river is in the hard crystalline rocks, and, according to the topographic map, both banks are about 30 or 35 feet high and the river 600 feet wide. A head of 18 or 20 feet could probably be developed here by a dam. The nearest city is Merrill, a place of over 9,000 inhabitants, distant only 8 miles by the Chicago, Milwaukee and St. Paul Railway.

MERRILL.

In the city of Merrill are two dams. The lower one, which has recently been repaired and partially rebuilt, is located between lots 1 and 3, sec. 12, T. 31 N., R. 6 E., and gives an average head of 14 feet. This power is owned by the Merrill Electric Light Company, which has installed and uses 600 horsepower. The remainder of the power is leased to the Lindore Paper Company, which in 1904 blasted out a new tailrace about 600 feet below the dam and has here installed 23 turbines under a 14-foot head, rated at 2,220 horsepower.

The second dam within the city limits of Merrill is located in sec. 10, T. 31 N., R. 6 E., about 2¼ miles above the paper mill, and is used for boom purposes only. It has a length of about 475 feet and develops an average head of 8 feet. A similar dam with an 8-foot head is located about 2 miles above, between secs. 8 and 9, T. 31 N., R. 6 E., and is also used only for boom purposes. Both dams are owned by the Wisconsin River Driving Association. As these dams are of little use at present, owing to the decline of the lumber interests, a company is now being formed to greatly improve the two powers by the construction of a new dam, to be located between secs. 9 and 16, T. 31 N., R. 6 E. It is stated that a head of 24 feet can be obtained here to run a new paper mill.

Wisconsin River is joined at Merrill by Prairie River. Between Merrill and Rhinelander Tomahawk and Pelican rivers add their waters from an aggregate drainage area of 3,300 square miles.

BILL CROSS RAPIDS.

The next power in order above Merrill is found at Bill Cross Rapids, in sec. 13, T. 32 N., R. 5 E., not far from the east quarter stake. Between this point and the foot of Grandfather Rapids the river descends 26½ feet. As the banks are reported high at this point it is probable that a head of 20 to 24 feet could be obtained. This dam site is distant 5 miles from the Chicago, Milwaukee and St. Paul Railway.

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[a] U. S. Geol. Survey topographic map.

[b] The power and riparian rights at these rapids are owned by G. D. Jones, Neal Brown, and Carl Mathie, of Wausau, Wis.

A. GRANDFATHER RAPIDS, WISCONSIN RIVER.

Ninety feet fall in 1⅛ miles.

B. BRUNETT FALLS, CHIPPEWA RIVER.

GRANDFATHER RAPIDS.

ı the 53 miles between the foot of the upper dam at Merrill and the foot of the Rhine-ler dam the river has a natural descent of 277 feet, an average of 5.2 feet per mile. :his stretch, besides several other fine powers, are included Grandfather Rapids, the est water power on the river, developed or undeveloped. These rapids begin in the . ¼ sec. 30, T. 33 N., R. 6 E., and extend to the SW. ¼ sec. 31, a distance of 1½ miles, are the most noted rapids on the river. A view of them is shown in Pl. III, *A*. The cent in this distance is 89½ feet. The high bank and the bed of the river are in the hard -Cambrian rock. For nearly thirty years the Wisconsin River Logging Association has intained three logging dams on these rapids. It is probable that the cheapest method developing this power would be to construct three dams of 30 feet head each, and that power could be best employed by paper mills. The site is about midway in the 20 mile etch from Merrill to Tomahawk.

About 1.5 miles above Grandfather Rapids are some small rapids where a 8.9-foot dam uld back the water to the foot of Grandmother Rapids.

GRANDMOTHER RAPIDS.

From the foot of the present Tomahawk dam to the foot of Grandmother Rapids, Wi-ısin River descends 41 feet, 6½ feet of which are concentrated at these rapids in a dis-ıce of 40 rods. According to a survey, 39 feet can be developed here. One dam site ıuld be near the south line of sec. 10, T. 33 N., R. 6 E., which is distant only 2½ miles m the Chicago, Milwaukee and St. Paul Railway at Irma.

TOMAHAWK DAM.

This dam, which has a head of 13.2 feet, is located in the SW. ¼ sec. 10, T. 34, N., R. 6 E. ıas a total pondage of over 4 square miles, the largest on the river, backing up the water the main river for about 6 miles, as well as in the tributaries. The steadying effect ich this dam exerts, together with that of several dams on adjoining lakes, must be very ıeficial. This power has been used for several years for running a large paper mill ated on the left bank and reached by spur tracks of the Chicago, Milwaukee and St. Paul ilway. The installation is 650 horsepower. During the summer of 1904 another paper l was erected on the opposite bank, taking its power from the same dam.

PINE CREEK RAPIDS.

'rom the foot of Whirlpool Rapids to the backwater of the Tomahawk dam, a distance 0 miles, the river has a nearly even descent of 23½ feet, 20 feet of which could be devel-d by one or possibly two dams. A 20-foot dam located about a mile east of the city Tomahawk, in the SE. ¼ sec. 25, T. 35 N., R. 6 E., would back the water up into Pine er. Most of the land thus to be overflowed belongs to lumbering companies or to the dley Company, of Tomahawk, Wis. This dam site is less than half a mile from the inette, Tomahawk and Western Railway.

WHIRLPOOL RAPIDS.

hese rapids extend from the west line of sec. 12, T. 35 N., R. 7 E., to the north line of coln County, a distance of about 2 miles, in which the river descends 15.4 feet. Between head of Whirlpool Rapids and the foot of Hat Rapids there is a descent of 12.63 feet. uitable dam at the foot of Nigger Island, in sec. 12, T. 35 N., R. 7 E., would develop a d of 28 feet. The banks are said to be high, with an abundance of rock and timber acent to the dam site. The drainage area at this point is 1,300 square miles. Three erent railroad lines are located within 3 or 4 miles of this site, and Tomahawk, a city of 0 population, is 7 miles west.

HAT RAPIDS.

Between the mouth of Pelican River and the foot of Hat rapids, in sec. 27, T. 36 N., R. 8 E., the Wisconsin descends about 22 feet. As the banks are high, a dam in sec. 27 between lots 4 and 5 could be made to develop about 20 feet of head. The drainage area at this point is 1,220 square miles. The Rhinelander Power Company has been formed to develop this power, and from Mr. A. W. Sheldon, Rhinelander, Wis., its attorney, the following facts were learned. A recent survey shows that the concrete dam should be located 13 rods north of the south line of sec. 27, T. 36 N., R. 8 E. It will be 264 feet long, with earthen dikes, in addition, of 80 and 250 feet. Such a dam would create a head of 20.3 feet. The site is only 5 miles from Rhinelander, a city of over 5,000 inhabitants, reached by both the Chicago and Northwestern and the Minneapolis, St. Paul and Sault Ste. Marie railways. The power could be either used at the site for a paper mill or electrically transmitted to Rhinelander for lighting and power purposes. The latter is stated as the present intention of the owners. An officer of the company states that all the contracts for construction and machinery have been let, and that the plant is expected to be in operation by September, 1905.

RHINELANDER DAM.

Between the foot of the present dam of the Rhinelander Paper and Pulp Company, in the city of Rhinelander, and the foot of Otter rapids, in sec. 36, T. 40 N., R. 9 E., a distance of about 35 miles, the river descends 79.2 feet. The dam develops 30 feet of this descent, and the power is used to run one of the largest paper and pulp mills on the river. The company has installed turbines rated at a total of 3,000 actual horsepower and has also 1,200 steam horsepower. The daily capacity of this mill is 45 tons of finished paper, 40 tons of pulp, and 40 tons of sulphite pulp.

The river above this point has a drainage area of about 940 square miles. Above Rhinelander the river banks are lower and the opportunities for developing large powers few. In the 35 miles between Rhinelander and the source there are two rapids, called Rainbow rapids and Otter rapids. In this distance, according to the United States engineers,[a] between the head of Otter rapids and a point about a mile above the mouth of Pelican River, the descent of Wisconsin River is only 57 feet, or about 1.62 feet per mile.

RAINBOW RAPIDS.

These rapids are of small extent. They are located in sec. 6, T. 38 N., R. 8 E., and a head of 6 to 10 feet could be secured.

OTTER RAPIDS.

The most important power above Rhinelander is at Otter rapids, where a logging dam with a head of about 10 feet was early constructed. The rapids proper descend 16 feet,[a] so that a head of this amount or more could be developed. The dam site is between lots 6 and 8, sec. 36, T. 40 N., R. 9 E. The drainage area above this point is about 500 square miles.

According to the Chicago and Northwestern Railway, the Wisconsin River at Conover, in sec. 9, T. 41 N., R. 10 E., has an elevation of 1,644 feet above the sea. This would give a fall of 66 feet in the 24 miles between Conover and the head of Otter rapids.

TRIBUTARIES OF WISCONSIN RIVER.

GENERAL STATEMENT.

The watershed line on each side of the Wisconsin Valley is between 300 and 400 feet above the main river, and as the tributaries have to descend this distance in a length of 50 or 60 miles they have many rapids and available powers. In the upper portion of

[a] Rept. Chief Eng., U. S. Army, 1881, p. 1824.

their courses the tributaries flow over the hard pre-Cambrian rock, giving many rapids. The lower valleys, however, are filled by continued erosion, so that with few exceptions, no powers are found here.

The length and drainage area of certain streams tributary to Wisconsin River are shown in the following table:

Principal tributaries of Wisconsin River.

River.	Length.	Drainage area.
	Miles.	*Sq. miles.*
Pelican	25	262
Tomahawk	50	714
Rib	50	498
Eau Claire	50	423
Eau Pleine	50	377
Yellow	70	946
Lemonweir	50	588
Baraboo	70	655
Kickapoo	75	760

Only Kickapoo, Baraboo, and Lemonweir rivers and their branches have been as yet fully or even largely developed, but the present rapid settlement of this northern region is fast bringing a demand for the utilization of these valuable water-power resources. While these powers are small as compared with those on the main river, in the aggregate they are large, and their wide distribution makes them of still greater value. In some cases, because of the ease with which they can be developed and controlled, manufacturers seem to prefer them to the larger but more expensive powers on the parent river. An example of this is seen in the present power developments on Prairie River.

ST. GERMAIN RIVER.

Although but 20 miles long, St. Germain River has at least three good dam sites located as follows: (1) SW. ¼ sec. 31, T. 41 N., R. 8 E.; (2) near the outlet of Big St. Germain Lake, sec. 32, T. 40 N., R. 8 E.; and (3) near the northeast corner of sec. 18, T. 39 N., R. 8 E. At the second dam site a head of 20 feet and at the third site a head of 26 feet are reported as feasible.

TOMAHAWK RIVER.

This river rises in about 40 lakes with elevations of from 1,540 to 1,575 feet above the sea, the largest of which is Tomahawk Lake, with an area of 7 square miles. The river joins the Wisconsin at Tomahawk after a course of about 50 miles.

The dam in Wisconsin River at Tomahawk backs the water in Tomahawk River to an elevation of 1,442 feet, so that the remaining descent is about 120 feet, or 2.4 feet per mile, nearly half of which is concentrated in four rapids. Only one of these has been developed for power purposes, the dam being located about 2 miles above the mouth of the river, where a head of about 18 feet is obtained. At present only 300 horsepower are here utilized, in a tannery belonging to the United States Leather Company.

Eight miles above this dam, in lots 5 and 6, sec. 21, T. 36 N., R. 6 E., are the Prairie rapids, with a descent of 20 feet; 10 miles above, in lots 1 and 4, sec. 17, T. 37 N., R. 6 E., are the Halfbreed rapids, with descent of 8 feet; and 12 miles still farther upstream, in sec. 27, T. 38 N., R. 5 E., are the Cedar rapids, with descent of 12 feet.

PELICAN RIVER.

This river rises in a series of lakes, the largest being known by the same name, at an elevation of 1,590 feet above the sea. The river flows west and joins the Wisconsin near

Rhinelander, after descending about 50 feet in its length of 25 miles. The following table shows the location of promising dam sites, none of which are as yet developed:

Dam-site locations on Pelican River.

	Possible head (feet).
Between lots 4 and 6, sec. 4, T. 36 N., R. 10 E.	6 to 8
SW. ¼ sec. 17, T. 36 N., R. 10 E.	6
Between lots 3 and 4, sec. 26, T. 36 N., R. 9 E.	10
Between lot 1, sec. 21, and lot 1, sec. 22, T. 36 N., R. 9 E.	12

PRAIRIE RIVER.

Although Prairie River has a drainage area of only 214 square miles and is without lakes at its upper headwaters, its water powers are of sufficient importance to have already attracted capital for their development. At the eastern limits of the city of Merrill a dam 200 feet long is being rebuilt so as to give a head of 21 feet. This dam is owned by the Prairie River Power and Boom Company. Nine miles northeast, in sec. 13, T. 32 N., R. 7 E., at a point where the river has worn a deep channel in the rocks, forming dalles, a masonry dam to furnish a head of 72 feet is now being built by the same company. This power will be transmitted electrically to the lower dam for use in a paper mill now under construction.

In sec. 14, T. 33 N., R. 8 E., are smaller dalles, where a head of 20 feet may be obtained.

RIB RIVER.

Rib River rises in two small lakes, the larger of which, Rib Lake, has an elevation of about 1,556 feet. After a course of about 50 miles, the Rib joins Wisconsin River a mile below the city of Wausau. Its total descent is 400 feet, an average of 8 feet to the mile. A considerable part of this descent is concentrated in the middle third of its length.

The first power is found at Marathon, 10 miles from its mouth, where a dam about 80 feet long develops a head of 18 feet. About 5 miles above, in the city of Rib Falls, a dam 100 feet long develops a head of 20 feet. In sec. 24, T. 30 N., R. 4 E., there is an undeveloped power with a head of 18 feet.

EAU CLAIRE RIVER.

The Eau Claire enters Wisconsin River 2 miles below the mouth of Rib River, and from the opposite (eastern) side. It has a smaller drainage area than that of the Rib, and a much larger proportion of its descent is distributed in its lower part.

A total of 148 feet is concentrated at the following points, given in order from the mouth of the river.[a]

Dam-site locations on Eau Claire River.

Location.	Head.	Remarks.
	Feet.	
Schofield, sec. 12, T. 28 N., R. 7 E.	12	Developed (old mill abandoned).
Manser's, sec. 10, T. 28 N., R. 8 E.	25	Developed, but only part used.
Old Kelley, sec. 13, T. 28 N., R. 8 E.	25	Developed for logging.
Barnards rapids, sec. 23, T. 29 N., R. 9 E.	22	Undeveloped.
The Dalles, sec. 7, T. 29 N., R. 10 E.	40	Do.
Three Rolls, sec. 34, T. 30 N., R. 10 E.	12	Do.
Little rapids, sec. 22, T. 30 N., R. 10 E.	12	Do.

The first three powers are adjacent to the Chicago and Northwestern Railway, and are used chiefly for boom purposes.

[a] Authority: D. L. Plummer, C. E.

EAU PLEINE RIVER.

This river has a narrower and smaller drainage area than either the Rib or the Eau Claire and is entirely devoid of lakes. Like the latter, it has considerable descent concentrated in its lower reaches, one power with a 15-foot head being located within 2 miles of its mouth. Following is a summary of its powers:

Dam-site locations on Eau Pleine River.

Location.	Head.	Remarks.
	Feet.	
Sec. 18, T. 26 N., R. 6 E	15	Undeveloped.
Sec. 24, T. 26 N., R. 6 E	15	Do.
Sec. 13, T. 27 N., R. 3 E	15	Do.
Sec. 4, T. 27 N., R. 3 E	10±	Developed.
Sec. 24, T. 28 N., R. 2 E	10±	.....

BLACK RIVER.

TOPOGRAPHY AND DRAINAGE.

Black River, hemmed in by the Chippewa on the west and the Wisconsin on the east, is restricted to a long and narrow watershed of about 2,270 square miles,[a] with an average width of only 20 miles. At one point the branches of Chippewa River extend to within a quarter of a mile of Black River. Unlike that of the Chippewa, about a third of the Black River drainage area is in the comparatively level sandstone region, so that the maximum watershed available for water powers, namely, at Black River Falls, is only 1,570 square miles.[a] The watershed narrows rapidly as the river is ascended, and at Neillsville, 22 miles in an air line from Black River Falls, the drainage area is reduced to only 729 square miles.[a] Were it not for this small watershed, the steep gradient of the river and its high, rocky banks would insure large water powers. Black River rises at an elevation of about 1,400 feet above sea level, and after a sinuous course of over 140 miles joins Mississippi River at La Crosse. The total descent in this distance is 772 feet, with details as shown in the following table:

Profile of Black River from its mouth near La Crosse to near Withee.[b]

No.	Station.	Distance.		Elevation above sea level.	Descent between points.	
		From mouth.	Between points.		Total.	Per mile.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
1	La Crosse (near)	.....	.....	628	.....	.....
2	Black River Falls:					
	Below dam	55.0	55.0	749	121	2.2
3	Above dam	55.0	.0	763	14	.....
4	Chicago, St. Paul, Minneapolis and Omaha Railroad bridge	58.0	3.0	766	3	1.0
5	Halls Creek, mouth of	61.6	3.6	776	10	2.8
6	Halcyon	67.0	5.4	793	17	3.1
7	Hatfield railroad bridge	71.2	4.2	838	45	10.4
8	East Forks, mouth of	74.2	3.0	846	8	2.7
9	Dells dam, below	77.5	3.3	874	28	8.5

[a] Census report, vol. 17, 1880, p. 87.
[b] Authority: No. 1 (low-water elevation), Mississippi River Commission; 2 to 22, Joint Survey of Wis. Geol. and Nat. Hist. Survey and United States Geological Survey.

Profile of Black River from its mouth near La Crosse to near Withee—Continued.

No.	Station.	Distance.		Elevation above sea level.	Desent between points.	
		From mouth.	Between points.		Total.	Per mile.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
10	Wedges Creek, mouth of	78.5	1.0	93	19	19.0
11	Cunningham Creek, mouth of	84.8	6.3	909	16	2.5
12	Center sec. 22, T. 24 N., R. 2 W.	86.8	2.0	929	20	10.0
13	O'Neill Creek, Neillsville	0.8	4.0	989	60	15.0
14	Bridge, secs. 9 and 16, T. 25 N., R. 2 W	98.8	8.0	1,034	45	5.6
15	Bridge, secs. 21 and 28, T. 27 N., R. 2 W	103.5	4.7	1,070	36	7.9
16	Bridge, Fairchild and Northeastern Rwy	107.8	4.3	1,094	24	5.6
17	Site New Greenwood dam	109.3	1.5	1,105	11	7.3
18	Between secs. 27 and 28, T. 27 N., R. 2 W	110.3	1.0	1,107	2	2.0
19	Hemlock dam, 600 feet below	113.5	3.2	1,132	25	8.0
20	Hemlock dam, above	113.6	.1	1,151	19	.....
21	Bridge, secs. 20 and 29, T. 29 N., R. 2 W	119.6	6.0	1,167	16	2.7
22	Bridge, Wisconsin Central Rwy., west of Withee	125.1	5.5	1,187	20	3.6

In the 55 miles below the city of Black River Falls the river flows through the sandstone country in a wide valley with low banks, making dam construction very expensive, if not entirely impracticable. In the 40 miles next above Black River Falls the river has worn its bed into the hard, crystalline rocks, which rise from 10 to 60 feet or more from the water, frequently in nearly vertical walls. The descent in this distance is 337 feet, nearly 9 feet to the mile. It is only in this stretch that important water powers occur. In the upper third of the valley the crystalline rocks frequently outcrop, but the resulting rapids are of less importance. The United States Geological Survey maintained a gaging station on Black River at Melrose for nine months in 1903, but as the station proved unsatisfactory it was abandoned August 1, 1903. Such measurements and observations as were taken are given below:

Discharge measurements of Black River near Melrose, Wis., in 1903.

Date.	Hydrographer.	Gage height.	Discharge.
		Feet.	*Second-feet.*
January 15	L. R. Stockman	4.30	[a] 508
February 7	do	4.30	[a] 508
April 4	do	5.90	2,982
May 1	do	11.00	10,931
June 13	do	3.90	842

[a] Frozen.

an daily gage height, in feet, of Black River near Melrose, Wis., December 4, 1902, to August 1, 1903.

Day.	1902.	1903.							
	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
.....	.....	5.05	4.10	4.30	5.10	11.00	7.60	3.60	3.75
.....	.....	5.00	4.10	4.35	4.85	10.00	.....	6.70	.....
.....	.....	4.90	4.10	4.40	5.30	10.25	.....	11.20	.....
.....	3.75	4.75	4.10	4.45	5.65	10.50	.....	10.90	.....
.....	3.95	4.60	4.10	4.60	5.90	9.65	6.00	13.00	.....
.....	4.00	4.60	4.20	4.75	6.50	9.05	4.70	12.30	.....
.....	3.80	4.50	4.20	(a)	6.65	8.15	4.40	10.20	.....
.....	4.35	4.50	4.20	6.25	6.50	7.00	4.30	7.90	.....
.....	4.35	(a)	4.20	8.20	6.20	6.95	4.25	6.90	.....
.....	4.30	4.40	4.20	9.30	5.50	6.55	4.00	7.40	.....
.....	4.35	4.40	4.30	9.70	5.60	6.10	4.00	8.70	.....
.....	4.20	4.40	4.25	10.75	.....	6.65	3.95	7.20	.....
3.....	4.20	4.40	4.20	12.05	5.45	10.60	3.95	6.70	.....
4.....	4.10	4.40	4.20	12.55	5.60	12.00	3.80	6.20	.....
5.....	4.15	(a)	4.20	11.55	5.95	10.90	3.80	5.80	.....
6.....	4.10	4.30	4.10	9.85	5.85	9.15	3.80	5.30	.....
7.....	4.00	4.30	4.15	9.40	6.05	7.80	3.70	4.50	.....
8.....	4.00	4.30	4.00	10.35	5.60	6.55	3.70	4.20	.....
9.....	4.05	4.30	3.95	11.95	5.00	6.50	3.70	4.10	.....
0.....	4.25	4.20	3.90	13.40	5.15	6.40	3.70	4.00	.....
1.....	4.60	4.20	3.90	12.90	4.50	6.30	3.70	4.00	.....
2.....	4.95	4.20	4.00	11.40	4.65	5.90	3.70	4.00	.....
3.....	5.80	4.20	4.00	9.65	4.30	6.50	3.70	3.90	.....
4.....	6.05	4.20	4.00	8.05	4.30	5.70	3.60	3.90	.....
5.....	5.85	4.20	4.05	7.65	4.35	5.80	3.60	3.90	.....
6.....	5.80	4.20	4.10	6.65	4.65	5.95	3.50	3.75	.....
7.....	5.65	4.20	4.20	6.02	.85	8.40	3.50	3.90	.....
8.....	5.50	4.20	4.35	6.55	5.00	11.85	3.50	4.20	.....
9.....	5.35	4.20	.....	5.70	5.65	12.60	3.50	4.00	.....
0.....	5.20	4.20	.....	6.55	6.80	10.95	3.50	3.80	.....
1.....	.....	4.10	.....	5.30	.....	9.50	.....	3.75	.....

a Observer absent.

A gaging station was established by the United States Geological Survey at Neillsville pril 7, 1905, and the following data have been collected:

Discharge measurements of Black River at Neillsville, Wis., in 1905.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Square feet.*	*Feet per second.*	*Feet.*	*Second-feet.*
pril 7.....	Hanna and Clapp.....	192	1,021	3.5	7.7	3,279
ay 24.....	S. K. Clapp.....	165	471	2.18	4.95	1,024
une 13.....	M. S. Brennon.....	192	945	3.15	7.26	2,978
uly 11.....	.....do.....	161	392	1.56	4.25	612
ugust 11.....	.....do.....	151	242	.93	3.3	225
eptember 25.....	F. W. Hanna.....	163	419	1.86	4.35	780

NOTE.—*Width* is the actual width of water surface, not including piers. *Area of section* is the total area of the measured section, including both moving and still water.

Mean daily gage height, in feet, of Black River at Neillsville, Wis., for 1905.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	3.4	3.7	4.4	2.7	3.3	3.5	3.7	4.0
2	.....	3.4	3.3	4.4	2.6	3.2	3.5	3.5	4.2
3	.....	4.1	3.2	4.9	2.6	3.5	3.4	3.5	3.8
4	.....	5.3	7.7	6.5	2.6	3.4	3.4	3.5	3.7
5	.....	5.2	14.2	8.4	2.9	3.6	3.0	3.5	3.8
6	8.2	4.9	19.8	8.0	2.7	3.2	3.0	3.7	3.5
7	7.7	5.0	16.5	6.8	4.2	3.1	3.1	4.1	3.5
8	6.9	4.6	11.5	5.9	4.0	3.0	2.7	4.1	3.4
9	6.2	4.6	8.8	5.3	4.0	2.9	2.4	3.9	3.3
10	6.0	5.9	7.6	4.7	3.5	2.8	3.1	3.8	3.4
11	5.7	6.6	8.6	4.2	3.3	2.7	3.0	3.7	3.4
12	5.5	6.7	8.0	3.8	3.3	2.8	3.0	3.7	3.5
13	5.1	6.2	7.1	3.9	3.3	2.7	3.0	3.6	3.4
14	4.8	10.7	6.2	4.0	3.3	2.7	3.0	3.5	3.4
15	4.6	10.1	5.5	4.8	3.2	4.3	4.0	3.4	3.5
16	4.3	9.2	5.8	4.5	3.0	6.0	4.9	3.4	3.4
17	3.9	8.7	11.2	4.0	2.9	6.0	5.4	3.4	3.3
18	3.8	8.2	10.7	3.8	3.0	6.1	5.5	3.4	3.0
19	4.2	6.6	8.6	4.2	3.0	8.6	5.6	3.4	3.0
20	3.9	6.0	7.0	4.3	3.0	8.3	6.6	3.3	3.2
21	3.2	5.3	6.0	4.0	3.2	7.5	6.9	3.2	3.1
22	3.1	5.1	5.2	3.8	3.5	6.3	6.5	3.2	3.1
23	3.1	4.9	4.5	3.3	3.4	5.8	5.9	3.2	3.3
24	3.5	4.7	4.1	3.1	3.6	4.7	5.5	3.5	3.5
25	3.4	4.3	3.9	3.1	3.4	4.2	5.0	4.2	3.5
26	3.4	4.2	3.7	3.0	3.3	3.9	4.6	4.6	3.5
27	3.4	4.1	3.5	2.9	3.2	3.8	4.4	4.5	3.4
28	3.4	3.9	3.3	2.9	3.0	3.7	4.1	4.3	3.4
29	3.4	3.9	3.3	2.8	3.4	3.6	3.9	3.9	3.4
30	3.4	3.8	3.5	2.8	3.5	3.8	3.7	3.7	3.5
31	.....	3.8	.....	2.7	3.3	.....	3.6	.....	3.5

NOTE.—No ice record at this station.

Rating table for Black River at Neillsville, Wis., from April 6 to December 31, 1905.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.00	150	4.80	990	6.60	2,310	8.40	4,120
3.10	177	4.90	1,055	6.70	2,395	8.50	4,230
3.20	205	5.00	1,120	6.80	2,480	8.60	4,340
3.30	235	5.10	1,185	6.90	2,570	8.70	4,460
3.40	267	5.20	1,250	7.00	2,660	8.80	4,580
3.50	301	5.30	1,315	7.10	2,750	8.90	4,700
3.60	338	5.40	1,385	7.20	2,850	9.00	4,820
3.70	379	5.50	1,455	7.30	2,950	9.10	4,940
3.80	424	5.60	1,525	7.40	3,050	9.20	5,060
3.90	473	5.70	1,600	7.50	3,150	9.30	5,180
4.00	525	5.80	1,675	7.60	3,250	9.40	5,300
4.10	579	5.90	1,750	7.70	3,350	9.50	5,420
4.20	635	6.00	1,825	7.80	3,460	9.60	5,540
4.30	692	6.10	1,905	7.90	3,570	9.70	5,660
4.40	750	6.20	1,985	8.00	3,680	9.80	5,780
4.50	810	6.30	2,065	8.10	3,790	9.90	5,900
4.60	870	6.40	2,145	8.20	3,900	10.00	6,020
4.70	930	6.50	2,225	8.30	4,010		

The above table is applicable only for open-channel conditions. It is based on six discharge measurements made during 1905. It is well defined between gage heights 3.3 feet and 7.7 feet. Beyond the limits of the table the discharge is only approximate.

Estimated monthly discharge of Black River at Neillsville, Wis., for 1905.

Month.	Discharge in second-feet.		
	Maximum.	Minimum.	Mean.
6-30)	3,900	177	1,036
	6,910	267	1,768
	23,060	205	3,840
	4,120	80	884
t	635	60	229
ıber	4,340	80	918
r	2,570	20	750
ıber	870	205	392
ber	635	150	292

WATER POWERS.

many years since Black River was used for lumbering, and as the surrounding country settled, it seems likely that the near future will see a demand for the available water s. These powers, while not of the largest, are so situated as to be cheaply developed. ver has no large tributaries, but nearly all its numerous small feeders are now developed ed to run grist and saw mills. At the present time several projects are being exploited look to the employment of these powers by interurban electric railroads and other rises in near-by cities.

BLACK RIVER FALLS.

first dam in the river is at Black River Falls and is of timber construction. The developed is owned by the city of Black River Falls, with turbines working under a f 13 feet, and by J. J. McGillivray, with turbines under a head of 16 feet. The present e could be lowered 3 or 4 feet, and the crest of the dam could be raised the same t without flooding. This improvement would give a total head of 20 feet. The es now installed develop about 345 horsepower, which is used to run an electric-light a sash and door mill, a wagon shop, and a gristmill.

ut 1½ miles below the above-described dam is the site of an old sawmill dam, 300 feet which at one time was made to develop a head of 7 feet.

BLACK RIVER FALLS TO NEILLSVILLE.

ause of the high, rocky banks and high gradient of this river, dams of 15 to 20 feet ould be installed nearly every 2 or 3 miles between Black River Falls and Neillsville, ly a few of the largest undeveloped powers will be described.

first dam site above Black River Falls is located near the east line of sec. 2, T. 21 N., W., just below the Chicago, St. Paul, Minneapolis and Omaha Railway bridge. At oint the rocky banks form a narrow gorge and are high enough to furnish a head of 30 more. By the use of a short canal this head could probably be increased. This site s to the Black River Improvement Company, of La Crosse, Wis. Another unde- d power, similar in all respects, for which a charter has been granted, is at Halcyon, in , T. 22 N., R. 3 W. A 30-foot dam here would back the water nearly to Hatfield, 3 above. A still more important dam site is located at Hatfield, just above the bridge Green Bay and Western Railroad. According to surveys made recently it is le to obtain here a head of 50 feet, which could be increased to about 85 feet by means ng canal. Such a dam would create a large pondage by backing up the water for 7 This would cover up dam sites in sec. 35, T. 23 N., R. 3 W., and also the "Dells in sec. 18, T. 23 N., R. 2 W., near the mouth of Wedges Creek. At the latter site a f 25 feet could be easily secured.

In the 6 miles below Neillsville, between the mouths of O'Neill and Cunningham creeks, the river descends 80 feet, 42 feet of which can be easily developed at Ross Eddy rapids, where a large part of this gradient is concentrated. It has been proposed to build a crib dam 250 feet long, with a crest of 18 feet, at the head of these rapids, and then conduct the water through a canal 95 rods long (in earth), thereby cutting off a long bend of the river and giving a total fall of 42 feet.[a] The outlet of such a canal would provide a favorable power site, free from any injury from ice jams.

NEILLSVILLE.

The last important undeveloped water power, known as Westons Rapids and owned by V. Huntzicker, of Neillsville, Wis., is located in sec. 2, T. 24 N., R. 2 W., about 1½ miles above Neillsville. From the head of these rapids near the north line of the NW. ¼ sec. 2, to the south line of same section, a distance of about a mile, the river descends 21.2 feet.[a] The owner proposes to locate a crib dam 250 feet long, with a crest of 18 feet, near the center of the section, and by making use of a canal in earth 600 feet long to obtain a head of 24 feet. A franchise has recently been obtained from the city of Neillsville for the employment of this power in lighting the city and for other purposes.

HEMLOCK DAM.

The most important developed power on the upper river is in sec. 15, T. 27 N., R. 2 W. This dam, called the Hemlock dam, has a head which averages 12 feet. Four turbines are installed here, with a total of 175 horsepower, used to run a roller flouring mill. The dam was originally erected for lumbering purposes.

Because of the unusually steep gradient in the branches of Black River a water power of from 10 to 20 feet can be located at frequent intervals on these streams. Several of the many mills in such locations report an available head of from 35 to 40 feet. In nearly every case timber and rock are found near the dam sites.

RAILROADS.

That portion of Black River containing the important powers is fairly well served by railroads. The river is crossed by the Chicago, St. Paul, Minneapolis and Omaha Railway four times, and once each by the Wisconsin Central Railway and the Green Bay and Western Railroad.

CHIPPEWA RIVER SYSTEM.

TOPOGRAPHY AND DRAINAGE.

The Chippewa drainage system has its source in over a hundred lakes, large and small, with many connecting swamps, near the Michigan boundary and only 20 miles from Lake Superior. The drainage area has a length of 180 miles, a maximum width of 90 miles, and an average width of nearly 60 miles. The general direction of the drainage, except in the extreme western part, is toward the southwest. Chippewa River unites with the Mississippi at the foot of Lake Pepin, after a course of 267 miles. The total area drained by the river is 9,573 square miles, of which about 6,000 include the most unsettled region of northern Wisconsin. This area includes the richest forests of the State, of both soft and hard timber. Although lumbering operations have been very active here for many years, considerable pine timber still remains, chiefly at the upper headwaters, but it is fast disappearing. Most of the large tracts of pine lands are owned by large corporations, and many of them are reached by long lines of logging railroads, which in many cases have been purchased by the trunk-line railroads and made a part of their systems. The extensive use of such railroads has greatly relieved the rivers of the burden of transporting logs, and correspondingly added to the value of the rivers for water-power purposes.

The main line of drainage runs very nearly along the central line of the basin, but the name of Chippewa River is not given to this continuation of the principal stream. The

[a] Authority: C. Stockwell, county surveyor.

iver divides 112 miles from the mouth; one branch, the prolongation of the line of drainage, alled the Flambeau, rises in the lakes near the Michigan line, at an elevation of a little over ,600 feet above the sea; the other branch, rising farther west and flowing more directly outh, receives the name Chippewa. The Flambeau drains 1,983 square miles, while hippewa River, above their junction, drains only 1,777 square miles. About 56 miles bove this junction the Chippewa again divides into East and West branches, the one flowing om the northeast, the other from the north, draining, respectively, 278 and 480 square iles.

The lakes of this region are situated in two widely separated groups, one in the extreme ortheastern part, at the headwaters of Flambeau River, and the other in the northwestern art, at the headwaters of what is known as the main stream and of Red Cedar River. he remainder of the area is almost devoid of lakes. The wooded regions, however, iclude very large areas of cedar and tamarack swamps.

GEOLOGY.

The pre-Cambrian crystalline rocks form the underlying strata in the area above Chippewa alls, while below that point they are replaced by the Cambrian sandstone. The entire rea above Chippewa Falls is covered with glacial drift, so that the rock appears only in ie river bed. The country is level or rolling. In the southern part of the area the rivers ave eroded deeply into the drift and rock, but in the northern portion they have not cut iuch below the surface.

With only a few exceptions (the most notable one at Eau Claire) all the many and nportant water powers on Chippewa River are found in the region of the pre-Cambrian rystalline rocks, but because of the deep drift the powers on the upper streams occur as owlder rapids.

PROPOSED RESERVOIR SITES.

According to detailed surveys made by United States engineers, this drainage area is avored with an unusual number of excellent sites for reservoirs. A list of these sites, with aluable data concerning them, is given in the following table:

Proposed United States Government dams on Chippewa River. [a]

Location and name.	Length.		Maximum height.		Drainage area above reservoir.
	Dam.	Dike.	Dam above low water.	Dike.	
East Branch Chippewa River:	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Sq. miles.*
Bear Lake	1,015	200	19.5	8.5	244.5
Little Chief Lake	710	.....	24.0	.....	57.6
West Branch Chippewa River:					
Moose Lake	1,235	160	25.7	1.5	214.3
Pakwawang Lake	900	.....	25.5	.....	257.2
Court Oreilles	260	100	6.5	5.0	114.0
Chippewa River, Paint Creek	620	.....	22.0	.....	3,943.1
Total	4,740	460	.....	.....	4,830.7
Butternut Creek, Butternut Lake	336	.....	10.0	.....	40.0
Manitouish River, Rest Lake	250	75	15.0	2.5	211.6
North Fork Flambeau, Bear Creek	2,500	2,000	15.0	10.5	154.5
Bore Flambeau:					
Round Lake	170	250	10.0	10.0	63.0
Squaw Lake	250	.....	9.0	.....	39.0
Turtle River, Park Lake	297	.....	15.0	.....	174.0
Grand total	8,543	2,785	.....	.....	5,512.8

[a] Rept. Chief Eng. U. S. Army, 1880, p. 1648.

Proposed United States Government dams on Chippewa River—Continued.

Location and name.	Supply (one-third of 30 inches rainfall).	Capacity of reservoir.	Surplus over reservoir capacity.	Supply from reservoir for 90 days.	Cost of dam and dike.
East Branch Chippewa River:	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Sec.-feet.*	
Bear Lake	5,677,951,910	1,113,148,856	4,564,803,054	143.1	$25,925
Little Chief Lake	1,337,627,935	771,332,009	566,295,926	99.2	40,702
West Branch Chippewa River:					
Moose Lake	4,976,626,153	2,-01,783,402	1,234,725,814	260.0	45,000
Pakwawang Lake	5,972,880,292	7,692,997,229		989.3	66,400
Court Oreilles	2,647,388,621	2,647,388,621	.....	340.4	2,402
Chippewa River, Paint Creek	91,569,456,760	505,336,720	91,064,120,040	65.0	60,000
Total	112,181,931,671	14,751,986,837	97,429,944,834	1,897.0	240,638
Butternut Creek, Butternut Lake	928,908,288	585,446,400	343,461,888	75.3	5,236
Manitouish River, Rest Lake	4,897,100,264	1,840,000,000	757,813,112	236.6	7,665
North Fork Flambeau, Bear Creek	3,107,280,000	5,406,567,152		695.3	47,520
Dore Flambeau:					
Round Lake	1,382,304,000	1,303,036,416	79,267,584	167.6	10,550
Squaw Lake	864,230,400	731,808,000	132,422,400	94.1	4,000
Turtle River, Park Lake	4,026,198,428	620,782,720	3,405,415,708	79.8	9,941
Grand total	127,387,953,051	25,239,627,525	102,148,325,526	3,245.7	325,530

It will be seen from the above table that the systematic operation of these proposed reservoirs for this purpose would increase the ordinary low-water flow of the river by 3,245 second-feet for ninety days a year, thus about doubling the present available water power of the river. Estimated upon a run-off of one-fourth of the annual rainfall, assumed at 30 inches, this increase would be 2,800 second-feet for ninety days.

Experiments now being carried on by the Government in Minnesota on five similarly constructed dams will doubtless determine whether the reservoir system at the headwaters of the Mississippi will be extended to include any of the above proposed dams. Probably the main obstacle to building such reservoirs at the present time by the Government is the fact that, owing to the settling up of this region, the land has now become very valuable. The total cost would seem to be prohibitive. That the owners of water powers are in favor of such Governmental control is certain. Besides adding to the amount of power, such a system would prevent, in large measure, the danger to dams by floods. The building of even a part of these dams would have marked economic value. Already private enterprise has developed some of the smaller of these reservoirs.

RAILROADS.

The logging interests of the river are controlled by the Chippewa Falls Lumber and Boom Company, with headquarters at Chippewa Falls, a thriving city of about 10,000 population. The largest city of this region is Eau Claire, population 17,517, situated at the junction of Eau Claire and Chippewa rivers. This city has numerous manufactories and sawmills, and is quite a railroad center. From its mouth to Chippewa Falls, Chippewa River is paralleled by the Chicago, Milwaukee and St. Paul Railway, and between Eau Claire and Chippewa Falls by the Chicago, St. Paul, Minneapolis and Omaha and the Wisconsin Central railways, besides an electric line. Chippewa River, above Chippewa Falls, is reached by the Chicago, St. Paul, Minneapolis and Omaha Railway for a distance of about 25 miles. In addition, the drainage area is crossed east and west by the Minneapolis, St. Paul and Sault Ste. Marie Railway and north and south by the Wisconsin Central Railway.

Several railroad lines are projected or being built in this section, and the agricultural and manufacturing interests are fast supplanting that of lumber. Where the timber has

been cut the land is being taken up by settlers, so that there is but little second-growth timber. The people seem prosperous, and numerous companies are on the point of investing large sums in the manufacturing interests of the neighborhood, thereby utilizing the undeveloped water powers.

RAINFALL AND RUN-OFF.

The extensive forests of this area combine with the numerous lakes and swamps to give a naturally uniform flow by preventing the rapid escape of the rainfall into the streams. Since 1903 the United States Geological Survey has maintained gaging stations near Eau Claire, on Chippewa River, and at Ladysmith, on the Flambeau. As a result of the operation of logging dams, the minimum discharge is found to be only 1.6 per cent of its maximum discharge for the year. The following tables give discharge data of Chippewa River at Eau Claire, covering the period from November 14, 1902, to August 12, 1905, and also a monthly summary of the same.

Discharge measurements of Chippewa River at highway bridge, Shawtown, near Eau Claire, Wis., 1902 to 1905.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
1902.		*Feet.*	*Square feet.*	*Feet per second.*	*Feet.*	*Second-feet.*
November 13	L. R. Stockman		3,666	3.88	8.70	11,134
December 6	do		2,809	1.03	4.45	2,871
December 28	do		2,793	1.09	4.60	3,063
1903.						
January 17	L. R. Stockman		2,509	.79	4.15	[a] 1,979
February 10	do		2,315	.77	3.80	[a] 1,778
March 9	do		2,877	1.32	4.85	[b] 3,818
April 6	do				7.40	10,688
May 5	do		5,726	4.62	11.85	26,458
June 15	do		3,105	1.64	4.70	4,107
July 10	do		4,761	3.61	9.25	17,167
August 20	do		2,372	1.83	5.13	4,336
September 5	do		3,626	2.21	6.20	8,032
October 13	do		4,637	3.25	8.77	15,087
November 24	do		2,281	1.54	4.90	3,511
1904.						
January 11[a]	E. Johnson, jr	310	2,429	.99	3.80	2,454
May 14	do	385	4,272	3.42	8.40	14,610
May 24	Johnson and Hanna	370	4,074	3.10	7.60	12,630
June 7	E. Johnson, jr	426	5,815	4.52	11.25	26,270
July 13	do	354	3,770	2.10	6.55	7,918
August 28	do	322	2,766	.82	4.20	2,274
September 19	do	329	3,122	1.47	5.25	4,581
October 12	F. W. Hanna	495	7,118	5.43	14.80	38,680
October 13	do	457	6,137	4.76	13.10	29,200
November 29	E. Johnson, jr	324	2,847	.80	4.44	2,281
1905.						
May 22	S. K. Clapp	200	4,004	3.66	8.80	16,110
June 14	M. S. Brennan	427	5,131	3.83	10.72	19,665
July 12	do	355	3,585	2.09	6.55	7,489
August 12		335	3,062	1.29	5.00	3,948

[a] Frozen. [b] Partly frozen.

NOTE.—Width is the actual width of water surface, not including piers. Area of section is the total area of the measured section, including both moving and still water.

Mean daily gage height, in feet, of Chippewa River near Eau Claire, Wis., November 11, 1902, to December 31, 1905.

Day.	1902.		1903.											
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	4.30	3.70	3.20	6.85	12.80	(a)	7.65	5.05	5.90	6.90	5.55	(a)
2	.....	.....	4.35	4.25	3.75	7.15	13.10	(a)	8.05	5.20	6.45	7.00	5.55	(a)
3	.....	.....	4.15	4.10	3.85	7.45	12.15	(a)	10.60	5.85	5.65	7.35	5.45	(a)
4	.....	.....	4.20	4.05	3.90	7.95	11.85	(a)	13.50	6.85	5.85	9.90	5.30	(a)
5	.....	4.50	4.40	4.10	3.75	7.85	11.55	(a)	15.30	7.50	5.75	11.25	5.25	(a)
6	.....	4.45	3.90	4.05	3.75	7.40	10.90	(a)	15.20	9.10	6.45	11.65	5.20	4.70
7	.....	4.00	4.15	4.15	3.85	7.50	10.30	6.85	13.75	9.00	5.85	11.60	5.15	4.65
8	.....	4.05	4.40	4.15	4.10	7.90	9.20	5.45	11.30	11.05	6.30	11.15	5.10	4.60
9	.....	4.05	4.20	4.00	4.60	8.55	9.15	6.45	10.30	6.70	8.00	11.35	5.05	4.60
10	.....	4.10	4.40	3.85	5.05	8.00	7.65	5.95	9.40	7.55	8.05	10.95	5.00	4.70
11	.....	4.25	4.80	3.80	5.80	7.60	8.95	6.50	10.10	7.25	9.15	9.95	5.00	4.55
12	.....	4.20	4.65	3.85	6.00	8.15	12.00	5.90	9.95	6.75	12.85	9.45	5.00	4.50
13	.....	4.45	4.75	3.90	7.05	7.70	13.25	9.25	8.90	6.85	14.00	9.00	5.05	4.70
14	13.70	4.25	4.60	3.90	8.20	7.65	13.40	3.75	8.10	6.90	16.75	8.80	5.30	4.85
15	10.20	4.55	4.85	3.90	8.05	7.80	13.25	4.65	7.80	9.65	17.85	8.45	5.40	4.75
16	12.40	4.25	4.30	4.50	7.00	7.80	11.85	4.95	7.20	5.10	18.50	7.75	4.95	4.70
17	13.05	4.30	4.20	4.10	7.00	7.50	10.45	4.95	6.50	6.80	17.45	7.70	4.95	4.60
18	12.60	4.10	4.30	4.15	7.55	6.75	9.90	4.90	8.80	6.65	15.50	7.40	4.25	4.65
19	11.35	4.30	4.65	4.30	11.80	6.65	9.15	4.30	5.95	6.00	13.45	7.55	4.40	4.65
20	9.60	4.25	4.40	4.25	13.95	6.85	9.15	5.15	6.70	5.10	11.80	7.05	4.15	4.60
21	8.50	4.30	4.50	4.20	13.65	6.80	9.30	4.70	6.15	5.15	10.50	7.05	4.20	4.60
22	7.55	4.25	4.35	3.35	12.65	6.65	9.50	4.20	5.70	7.50	9.95	6.75	4.35	4.80
23	7.40	4.50	4.35	3.80	11.70	6.40	9.05	4.20	5.60	5.60	9.15	6.70	4.85	4.70
24	7.15	4.70	4.45	4.15	10.45	6.40	9.10	4.15	6.00	5.10	7.80	6.55	4.95	4.80
25	7.00	4.30	3.50	4.05	9.40	8.60	9.85	4.25	9.20	5.15	7.60	6.30	4.95	4.60
26	6.45	4.90	4.20	3.90	8.75	6.55	10.20	4.15	5.25	5.25	7.00	6.15	4.90	4.40
27	6.20	5.10	4.10	3.95	8.40	7.15	12.50	6.75	5.05	4.70	7.65	5.95	4.85	3.40
28	6.00	4.60	4.10	3.85	7.75	7.00	15.15	4.20	5.20	5.45	7.05	6.10	4.60	3.70
29	5.75	4.50	3.85	.....	7.60	7.30	16.70	4.00	5.15	5.60	7.05	6.10	.....	3.60
30	5.55	4.85	4.15	.....	7.15	11.70	16.10	4.95	5.15	5.20	7.05	6.10	.....	3.60
31	.....	4.50	4.25	.....	6.80	.....	.....	.....	5.10	5.60	.....	5.90	.....	3.40

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.[b]												
1	c 4.90	.....	.....	6.25	9.00	8.45	8.10	4.42	4.58	6.31	6.79	3.93
2	c 5.15	.....	.....	6.72	8.65	7.65	8.52	4.80	5.05	5.24	6.84	3.92
3	.....	.....	.....	6.50	8.63	7.65	8.28	4.38	8.18	8.27	6.80	3.93
4	c 5.00	.....	.....	6.52	8.28	8.85	8.02	4.78	7.52	5.65	6.61	3.45
5	.....	.....	d 4.80	6.60	8.10	9.00	10.32	4.32	8.30	5.30	5.91	4.42
6	.....	e 4.80	.....	7.17	8.03	10.95	10.12	4.12	7.30	5.27	6.41	4.28
7	.....	.....	.....	7.60	10.13	11.30	9.63	3.45	7.52	4.82	6.08	4.28
8	.....	.....	.....	9.10	8.50	10.85	8.93	4.62	7.12	9.12	5.35	4.28
9	c 4.80	.....	.....	9.67	8.83	9.85	7.22	5.10	6.72	7.86	5.35	4.37
10	.....	.....	.....	9.72	9.35	8.92	7.10	5.42	7.95	13.35	5.60	4.36
11	.....	.....	.....	9.70	9.25	7.95	7.20	5.35	5.03	15.07	5.36	4.35
12	.....	.....	e 4.95	9.32	8.85	7.80	6.72	4.38	5.28	14.93	5.02	4.34
13	.....	d 5.00	.....	9.05	8.78	7.80	6.60	4.12	5.42	13.15	6.27	4.39
14	.....	.....	.....	8.82	10.20	7.45	5.88	3.50	5.35	11.38	4.82	4.20

a Observer absent.
b River frozen over January 1 to March 18, 1904, but open about 200 to 300 feet above and one-fourth mile below bridge.
c Ice 2.0 feet thick at gage; 1.0 foot in middle of channel.
d Ice 2.5 feet thick at gage; 2.5 feet in middle of channel.
e Ice 2.0 feet thick at gage; 2.0 feet in middle of channel.

age height, in feet, of Chippewa River near Eau Claire, Wis., November 14, 1902, to December 31, 1905—Continued.

Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
.....	.....	.....	8.50	8.00	7.80	5.07	3.80	5.38	10.30	6.26	4.34
[a] 5.00	.....	.....	7.55	8.20	8.35	5.55	4.55	5.42	9.17	5.42	4.32
.....	.....	.....	7.25	7.55	6.25	5.35	4.82	7.10	8.10	5.30	4.15
.....	.....	.....	7.50	7.22	5.50	5.60	4.65	4.80	8.00	5.47	4.19
.....	[b] 5.10	4.45	8.38	7.55	5.10	5.50	4.78	4.89	7.08	5.20	4.53
.....	.....	4.07	8.20	6.93	6.20	5.10	7.20	4.27	6.85	4.98	4.29
.....	.....	4.45	8.13	10.30	6.50	5.47	5.25	4.30	8.35	5.28	4.34
.....	.....	4.37	7.45	6.30	5.90	5.05	4.75	4.35	9.25	5.23	4.37
[a] 5.00	.....	4.32	8.05	6.83	5.80	4.75	4.68	5.10	9.42	5.74	4.55
.....	.....	5.62	8.50	7.33	5.50	3.93	4.60	4.24	9.00	4.77	4.38
.....	.....	5.95	9.65	9.20	8.95	4.07	5.00	5.76	8.78	4.94	3.31
.....	.....	6.45	10.63	12.00	5.55	4.90	5.40	8.18	7.81	5.10	4.19
.....	[b] 5.30	6.10	10.45	13.48	7.75	4.80	8.15	7.61	8.02	4.85	4.55
.....	.....	5.72	9.18	13.63	7.60	5.00	3.58	6.93	7.22	4.55	([c])
[d] 4.70	.....	5.05	9.55	12.02	7.75	4.88	5.55	9.81	7.55	4.54	.....
.....	.....	5.10	9.03	10.67	7.50	6.45	4.92	6.65	7.30	4.46	.....
.....	.....	5.32	.....	9.20	.....	5.00	4.52	.....	6.85	.....	.....
([c])	.....	.....	12.00	6.80	6.30	6.80	6.80	6.50	5.15	5.70	4.75
4.36	.....	.....	10.20	5.80	6.80	7.40	5.75	6.20	5.55	6.15	5.15
.....	.....	.....	11.20	5.90	6.50	6.30	4.35	5.30	7.80	5.45	4.85
.....	.....	.....	10.50	6.50	8.20	6.20	4.35	6.10	5.55	5.75	5.65
.....	4.80	4.20	10.40	7.50	12.10	6.90	4.75	6.80	4.90	5.65	4.40
.....	.....	.....	10.80	6.60	19.20	10.40	5.10	6.50	4.90	5.75	5.40
.....	.....	.....	10.20	7.30	.....	10.60	5.25	6.10	7.50	6.10	5.40
.....	.....	.....	9.80	7.60	19.60	11.30	5.05	5.65	5.00	6.30	5.90
4.40	.....	4.50	9.20	7.30	17.30	10.10	5.30	5.75	4.85	6.05	5.85
.....	.....	.....	8.90	8.80	14.50	7.00	5.90	5.10	4.80	6.10	5.35
.....	.....	.....	8.70	7.80	13.00	8.10	4.90	4.90	5.50	6.50	5.30
.....	.....	4.30	7.40	7.90	12.60	6.90	5.45	5.35	7.90	5.50	5.30
.....	5.30	4.30	5.75	7.50	11.50	6.90	5.10	6.90	6.20	5.70	5.30
.....	.....	4.25	5.65	9.50	10.00	7.20	5.35	5.85	5.90	5.80	5.25
4.80	.....	4.10	6.10	10.70	9.40	7.10	5.70	5.40	5.25	5.20	5.00
.....	.....	4.50	5.75	12.20	8.80	7.60	4.45	5.55	6.40	6.20	4.60
.....	.....	4.50	6.20	12.90	8.70	6.80	4.45	7.70	7.35	5.50	4.70
.....	5.36	4.65	7.00	12.00	10.20	6.50	5.60	10.70	7.80	6.00	4.80
.....	.....	4.40	5.60	10.60	12.20	6.60	5.25	7.00	7.90	5.50	4.70
.....	.....	4.45	5.45	10.20	11.30	6.70	7.40	10.10	8.95	5.45	4.70
.....	.....	4.55	5.40	9.20	10.50	6.00	7.30	10.80	8.50	5.40	4.65
4.67	.....	5.50	5.40	8.60	9.10	6.40	8.90	10.30	8.65	4.60	4.85
.....	.....	6.20	5.05	8.60	9.00	5.70	5.85	9.20	8.35	5.20	4.55
.....	.....	7.10	5.30	8.00	8.80	6.10	6.20	8.40	7.90	5.00	4.60
.....	4.95	7.80	5.30	8.10	8.20	5.75	6.40	6.50	7.55	5.20	4.10
.....	.....	8.90	6.30	7.50	7.30	5.55	8.30	8.50	7.20	5.70	4.80
.....	.....	10.40	5.50	7.70	7.50	4.90	5.30	6.00	7.10	6.05	4.60
.....	.....	11.80	4.80	7.00	8.70	4.45	5.00	6.00	7.00	5.70	4.65
5.17	.....	13.20	5.05	7.10	7.80	5.30	7.80	7.90	6.60	5.70	4.55
.....	.....	13.60	4.85	7.20	5.75	4.45	6.20	6.20	6.50	5.00	4.70
.....	.....	12.90	.....	6.90	.....	4.35	6.20	.....	6.40	.....	4.70

nicker at gage: 1.0 foot in middle of channel.
nick at gage: 2.5 feet in middle of channel.
December 28 to 31.
nick at gage: 2.0 feet in middle of channel.
entirely *across at gage January* 1 to February 28; March 1 to 17, ice gradually disap-
ess of ice, 2 to 2.5 feet. Gage heights are to water surface in a hole in the ice.

Rating table for Chippewa River near Eau Claire, Wis., from November 30, 1902, to Mar 12, 1903.[a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.2	840	4.0	1,985	4.7	3,370	5.4	5,150
3.3	940	4.1	2,165	4.8	3,610	5.5	5,410
3.4	1,055	4.2	2,345	4.9	3,850	5.6	5,670
3.5	1,190	4.3	2,535	5.0	4,110	5.7	5,930
3.6	1,335	4.4	2,735	5.1	4,370	5.8	6,190
3.7	1,490	4.5	2,940	5.2	4,630	5.9	6,450
3.8	1,655	4.6	3,150	5.3	4,890	6.0	6,710
3.9	1,825						

[a] To be used only when river is frozen.

Rating table for Chippewa River near Eau Claire, Wis., from March 12, 1903, to December 1, 1903.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.8	2,160	5.7	6,290	7.6	11,310	11.0	23,310
3.9	2,340	5.8	6,530	7.7	11,610	11.2	24,070
4.0	2,530	5.9	6,770	7.8	11,910	11.4	24,830
4.1	2,730	6.0	7,010	7.9	12,210	11.6	25,500
4.2	2.930	6.1	7,270	8.0	12,510	11.8	26,350
4.3	3,130	6.2	7,530	8.2	13,150	12.0	27,110
4.4	3,330	6.3	7,790	8.4	13,790	12.5	29,010
4.5	3,540	6.4	8,050	8.6	14,450	13.0	30,910
4.6	3,760	6.5	8,310	8.8	15,130	13.5	32,810
4.7	3,980	6.6	8,570	9.0	15,810	14.0	34,710
4.8	4,200	6.7	8,830	9.2	16,530	14.5	36,610
4.9	4,420	6.8	9,090	9.4	17,250	15.0	38,510
5.0	4,640	6.9	9,350	9.6	17,990	15.5	40,410
5.1	4,860	7.0	9,610	9.8	18,750	16.0	42,310
5.2	5,090	7.1	9,890	10.0	19,510	16.5	44,210
5.3	5,330	7.2	10,170	10.2	20,270	17.0	46,110
5.4	5,570	7.3	10,450	10.4	21,030	17.5	48,010
5.5	5,810	7.4	10,730	10.6	21,790	18.0	49,910
5.6	6,050	7.5	11,010	10.8	22,550		

Rating table for Chippewa River near Eau Claire, Wis., from January 1 to December 31, 1904.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
4.0	1,780	5.1	4,390	6.4	8,100	9.0	16,680
4.1	1,980	5.2	4,660	6.6	8,720	9.5	18,380
4.2	2,180	5.3	4,930	6.8	9,350	10.0	20,080
4.3	2,390	5.4	5,200	7.0	9,990	10.5	21,780
4.4	2,610	5.5	5,480	7.2	10,650	11.0	23,480
4.5	2,840	5.6	5,760	7.4	11,310	11.5	25,210
4.6	3,080	5.7	6,040	7.6	11,970	12.0	26,960
4.7	3,330	5.8	6,320	7.8	12,630	13.0	30,500
4.8	3,590	5.9	6,610	8.0	13,290	14.0	34,480
4.9	3,850	6.0	6,900	8.5	14,980	15.0	40,000
5.0	4,120	6.2	7,490				

r table for Chippewa River near Eau Claire, Wis., from January 1 to December 31, 1905.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
3.50	750	5.40	4,830	7.60	10,290	11.40	22,410
3.60	960	5.50	5,050	7.80	10,870	11.60	23,160
3.70	1,170	5.60	5,280	8.00	11,450	11.80	23,950
3.80	1,380	5.70	5,510	8.20	12,030	12.00	24,750
3.90	1,590	5.80	5,740	8.40	12,610	12.20	25,550
4.00	1,800	5.90	5,970	8.60	13,200	12.40	26,350
4.10	2,010	6.00	6,200	8.80	13,800	12.60	27,150
4.20	2,220	6.10	6,430	9.00	14,400	12.80	27,950
4.30	2,430	6.20	6,660	9.20	15,000	13.00	28,750
4.40	2,640	6.30	6,900	9.40	15,620	13.20	29,560
4.50	2,850	6.40	7,140	9.60	16,260	13.40	30,390
4.60	3,070	6.50	7,380	9.80	16,920	13.60	31,240
4.70	3,290	6.60	7,630	10.00	17,600	13.80	32,110
4.80	3,510	6.70	7,880	10.20	18,280	14.00	33,000
4.90	3,730	6.80	8,130	10.40	18,960	14.20	33,900
5.00	3,950	6.90	8,390	10.60	19,640	14.40	34,800
5.10	4,170	7.00	8,650	10.80	20,320	14.60	35,700
5.20	4,390	7.20	9,180	11.00	21,000	14.80	36,600
5.30	4,610	7.40	9,720	11.20	21,690		

above table is applicable only for open-channel conditions. It is based on 15 discharge measure- made during 1904–5. It is well defined between gage heights 5 feet and 13 feet. The table has xtended beyond these limits.

Estimated monthly discharge of Chippewa River at Eau Claire, Wis., 1902 to 1905.

[Drainage area, 6,740 square miles.]

Date.	Discharge.			Run-off.		Rainfall.[a]
	Maximum.	Minimum.	Mean.	Per square mile.	Depth.	
1902.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Inches.*	*Inches.*
mber 14-29	.....	.....	14,835	2.20	1.39	5.82
nber 5-31	.....	.....	2,789	.41	.41	1.92
1903.						
ary	3,730	1,190	2,593	.38	.44	.45
uary	2,940	995	2,023	.30	.31	.86
h	34,520	840	11,573	1.72	1.98	2.28
	25,970	8,050	11,240	1.67	1.86	3.07
)	44,970	11,460	24,761	3.67	4.23	6.45
'	36,990	2,070	8,720	1.29	1.44	1.95
	39,650	4,750	14,698	2.18	2.51	7.70
ıst	23,500	3,980	8,602	1.28	1.48	5.35
mber	51,810	6,170	19,584	2.90	3.24	7.58
ber	25,780	6,770	13,524	2.01	2.32	3.57

ainfall for 1902 and 1903 is the average of the recorded precipitation at the following stations: ernut, Hayward, Medford, Barron, and Eau Claire; that for 1904 includes the same stations with ddition of Stanley and Prentice.
ay 31 estimated.
to 6, inclusive, estimated.

Estimated monthly discharge of Chippewa River at Eau Claire, Wis., 1902 to 1905—Continued.

Date.	Discharge.			Run-off.		Rainfall.
	Maximum.	Minimum.	Mean.	Per square inch.	Depth.	
1903.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Inches.*	*Inches.*
November	5,930	2,830	4,562	0.68	0.76	0.96
December	3,980	1,055	2,855	.42	.48	.84
The year	51,810	840	10,395	1.54	21.05	41.77
1904.						
January						.51
February						1.05
March 19–31	8,255	1,920	4,622	.686	.332	1.56
April	22,220	7,640	14,550	2.16	2.41	2.01
May	32,900	7,790	16,960	2.52	2.90	4.33
June	24,510	4,390	12,600	1.87	2.09	6.14
July	21,170	1,647	8,525	1.26	1.45	3.13
August	13,790	650	3,778	.561	.647	4.27
September	19,430	2,264	7,801	1.16	1.29	4.86
October	40,400	3,642	15,170	2.25	2.59	5.59
November	9,478	2,748	5,576	.827	.923	.17
December 1–27	2,960	380	2,230	.331	.332	1.70
The year						35.41
1905.						
March 18–31		31,240	2,640	13,510	2.00	1.04
April		24,750	3,510	10,184	1.51	1.68
May		28,350	5,740	12,666	1.88	2.17
June		60,520	5,625	20,368	3.02	3.26
July		22,050	2,535	8,626	1.28	1.48
August		14,100	2,535	5,867	.870	1.00
September		20,320	3,730	8,970	1.33	1.68
October		14,250	3,510	8,041	1.19	1.37
November		7,380	3,070	5,437	.807	.90
December		5,970	2,010	3,821	.567	.65

WATER POWERS.

CHIPPEWA BELOW JUNCTION OF FLAMBEAU RIVER.

Topography and drainage.—The following descriptions of the water powers on Chippewa River between its mouth and the junction with Flambeau River were largely obtained from a manuscript report of a hypsometric survey of this part of the river made by the United States Geological Survey during the summer of 1903.[a] Between the mouth of the river and Chippewa Falls a very careful primary level was run, while between Chippewa Falls and the mouth of the Flambeau, in addition to taking levels, a topographic survey was made of the river bank and the area immediately adjacent. Between the mouth of the Chippewa and that of the Eau Claire, a distance of 48.4 miles, this survey showed that there was a descent at low water of about 106 feet, or about 2.3 feet per mile. Because of the uniformity of this low gradient, and also because of the width of the stream and of the adjacent bottom lands, there are no opportunities for water powers until Eau Claire is reached. Details of descent and apportionment of drainage areas are shown in the following tables:

[a] The survey of that portion of the river between Watkins Landing, Minnesota, and Chippewa Falls Wis., was under the charge of Geographer J. H. Renshaw. Above Chippewa Falls the work was in charge of Geographer H. M. Wilson.

Profile of Chippewa River from its mouth to sources of East and West branches.[a]

Station.	Distance.		Elevation above sea-level.	Descent between points.	
	From mouth.	Between points.		Total.	Per mile.
	Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
Reeds Landing	0	0	[b] 680.0 [c] 664.0	.....	0
Shawtown	45.5	45.5	770.0	106.0	2.3
Eau Claire River, mouth	48.8	3.3	770.0	.0	.0
Dalles paper mills:					
Foot of dam	49.4	.6	772.0	2.0	3.3
Head of dam	49.4	10.0	793.0	21.0	.....
Chippewa Falls:					
Foot of dam	64.4	14.5	806.0	14.0	1.0
Head of dam	64.4	50.0	839.0	33.0	.....
Yellow River, mouth	69.9	5.5	852.0	13.0	2.4
Eagle rapids:					
Foot	72.4	2.5	854.0	2.0	.8
Head	73.6	1.2	867.0	13.0	10.8
Water level	75.1	1.5	871.0	4.0	2.7
Rapids, foot	77.4	2.3	881.0	10.0	4.3
Jim Falls:					
Foot	80.1	2.7	901.0	20.0	7.4
Head	81.0	.9	936.0	35.0	39.0
Colton rapids:					
Foot	82.3	1.3	942.0	6.0	4.6
Head	83.6	1.3	945.0	3.0	2.3
Bob Creek	87.3	3.7	954.0	9.0	2.4
Chevalley rapids:					
Foot	90.1	2.8	961.0	7.0	2.5
Head	91.3	1.2	966.0	5.0	4.2
Brunett Falls:					
Foot	91.4	.1	967.0	1.0	10.0
Head	92.4	1.0	993.0	26.0	26.0
Fisher River, mouth	93.9	1.5	995.0	2.0	1.3
Holcombe rapids:					
Foot	97.1	3.2	1,004.0	9.0	2.7
Foot of dam	97.6	.5	1,020.0	16.0	32.0
Head of dam, water level	97.6	.0	1,036.0	16.0	.....
Deertail Creek, mouth	104.1	6.5	1,036.0	.0	.0
Flambeau River junction	107.7	3.6	1,050.0	14.0	4.0
Bruce, sec. 28, T 32 N R. 6 W	124.2	16.5	1,059.0	9.0	.5
East and West branches junction	162.7	38.5	1,280.0	221.0	5.6
EAST BRANCH.					
Goose Eye rapids head (foot Little Chief Lake)	164.7	2.0	1,323.4	43.4	21.7
Snaptail rapids (Hunters Lake):					
Foot	166.7	2.0	1,325.2	1.8	.9
Head	168.2	1.5	1,368.8	43.6	29.0
Blaisdells Lake	170.7	2.5	1,374.5	5.7	2.3
Cedar rapids:					
Foot	173.2	2.5	1,404.0	29.5	11.8
Head	175.7	2.5	1,420.0	16.0	6.4
Bear Lake	178.2	2.5	1,432.9	12.9	5.1

[a] Authority: Nos. 1, Mississippi River Commission; 2–27, U. S. Geol. Survey; 28, David Kirk; 29–47 engineers.
[b] High water.
[c] Low water.

Profile of Chippewa River from its mouth to sources of East and West branches.—Continued.

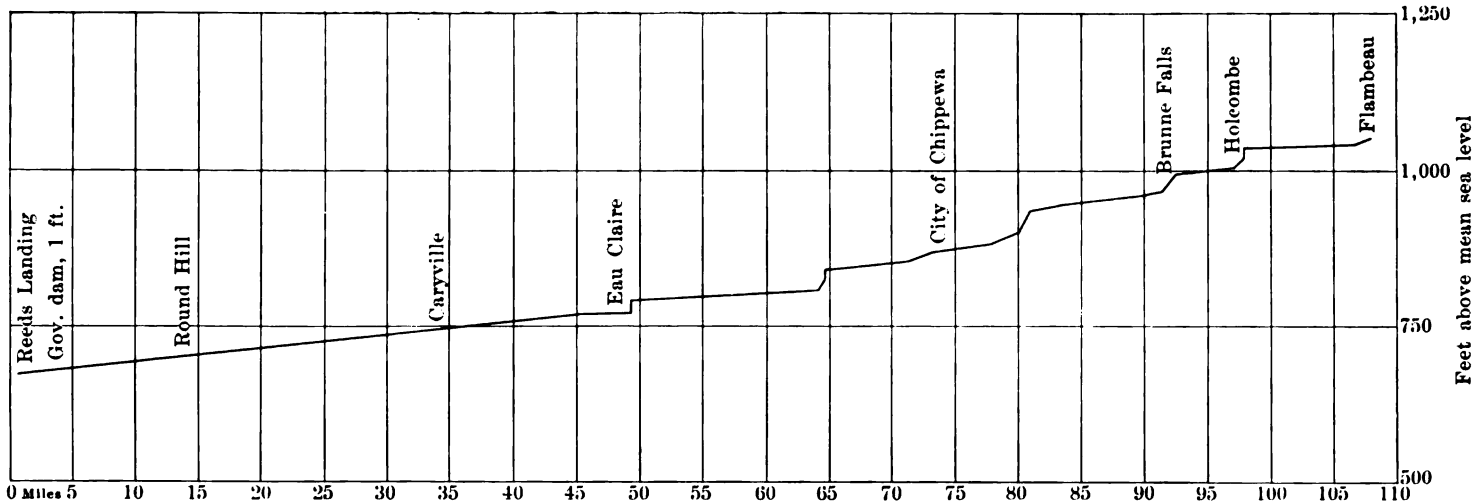
No	Station.	Distance. From mouth.	Distance. Between points.	Elevation above sea-level.	Descent between points. Total.	Descent between points. Per mile.
	EAST BRANCH.—Continued.	*Miles.*	*Miles.*	*Feet.*	*Feet.*	*Feet.*
37	River, water level	181.7	3.5	1,442.0	9.1	2.6
38	Pelican Lake	186.7	5.0	1,462.0	20.0	4.0
39	River, water level, sec. 19, T. 42 N., R. 2 W	190.2	3.5	1,463.8	1.8	.5
40	Glidden Station	201.7	11.5	1,509.3	45.5	4.0
41	Source of river	223.7	22.0±	.....	.....	.....
	WEST BRANCH.					
42	Proposed U. S. dam	164.5	1.8	1,286.0	6.0	3.3
43	Pakwawang Lake	168.7	6.0	1,287.2	1.2	.2
	Moose Lake:					
44	Proposed U. S. dam	178.7	10.0	1,358.8	71.6	7.2
45	Water level	178.7	.0	1,361.9	3.1	.....
46	Partridge Crop Lake	185.7	7.0	1,384.4	22.5	3.2
47	Source of river	205.7	20.0±	.....	.....	.....

Distances and drainage areas of Chippewa River.

River.[a]	Distance from the junction of East and West branches, map measure.	Drainage area above station.
	Miles.	*Sq. miles.*
East and West branches (junction)	0	757
Court Oreilles	14	988
Thornapple (above mouth)	36	1,383
Flambeau:		
Above mouth	53	1,777
Mouth	53	3,761
Yellow:		
Above mouth	90	4,926
Mouth	90	5,384
Eau Claire:		
Above mouth	113	5,760
Mouth	113	6,659
Red Cedar:		
Above mouth	142	7,004
Mouth	142	8,961
Chippewa	165	9,573

[a] Station is at mouth of river, unless otherwise stated.

Eau Claire.—The first dam site is located about 2½ miles below the mouth of Eau Claire River. According to a recent survey by the city engineer, a head of 7 feet could be obtained here. On account of its proximity to the city of Eau Claire, this power would have especial value. Before improvement there were two rapids in the river between Eau Claire and Chippewa Falls, one 1.25 miles above the Eau Claire, called the Lower Dalles, with a descent of 10½ feet in a little over 2 miles; the other about 4 miles below Chippewa Falls, called the Upper Dalles, with a descent of 9 feet in about 2 miles.



PROFILE OF CHIPPEWA RIVER FROM REEDS LANDING, MINN., TO FLAMBEAU, WIS.

ıe dam 2 miles above Eau Claire, owned by the Dells Paper and Pulp Company, is of square-timber, crib type on a sandstone foundation. It is about 600 feet long, 19 feet , 3 feet wide at the top, and with a base of about 8 feet. Eight splash boards are used ıe crest when necessary, giving a head of 26 feet. It would be possible to increase the ht of the dam so as to develop 32 feet, and a bill authorizing this increase is now (March,) pending before the State legislature. Such a dam would back the water nearly to pewa Falls, 15 miles above, greatly adding to an already very large pondage. This is most important manufacturing plant on the river. The turbine installation is rted as follows:

Dells Paper and Pulp Company's turbine installation, 2 miles above Eau Claire.

rpose.	Horsepower.
r mill	1,396
mill	4,918
tric light and power	1,632
erworks	300
	8,246

ippewa Falls.—In the 14½ miles between the Dells dam and Chippewa Falls no power are found, the river having a nearly uniform slope of 1 foot to the mile. At the latter , however, is a wooden dam 800 feet long, with a head of 30 feet, owned by the Chip- Falls Lumber and Boom Company. This dam supplies power for a large sawmill also a plant furnishing the city of Chippewa Falls with water and electric light. The could be made several feet higher, as the local conditions are favorable, but this d interfere with a proposed plant at Paint Creek rapids, 2½ miles upstream, to which t the water now backs. The owners have developed only about 20 feet of head, but could be increased to the full head of 30 feet by blasting and cleaning out the river to vagon bridge below. The power and light company leases 1,000 horsepower, using a of 29 feet.

ıe next rapids, known as Paint Creek rapids, are 2½ miles above the Chippewa Falls . A flooding dam 526 feet long, with a crest 10½ feet above low water, was formerly ıtained here. A dam about 800 feet long, with a head of 14 feet, could be constructed e foot of the rapids at this point. The banks and bed appear to be sand, intermingled large bowlders. Stone for construction is abundant and near at hand, and it is that a rock foundation could be easily obtained.

ıgle rapids, 4½ miles farther upstream, in lot 3, sec. 16, T. 29 N., R. 8 W., is a good for a dam, owned by F. G. & C. A. Stanley, of Chippewa Falls. A dam 60 feet long 20 feet high would back the water three fourths of a mile above the city of Chippewa , where O'Neils Creek enters from the west. One mile above the mouth of O'Neils , in sec. 10, T. 29 N., R. 8 W., is a gorge 700 feet wide, where a 25-foot dam would solid sandstone for foundations and abutments and would back the water almost ıe foot of Jim Falls, 5 miles above. Such a dam would develop 5,000 theoretical power.

m Falls.—Near the small station of Jim Falls, on the Chicago and Northwestern Rail- occurs the best opportunity for water-power development on Chippewa River. It is d by W. L. Davis, of Eau Claire. Formerly an old flooding dam was located here. river flows over a series of granite ledges 1 to 4 feet high, while the banks seem to be e same rock, covered by a few feet of sandy soil. This power is now under develop- t, a company having purchased all the land needed. The proposed dam, 28 feet high, be located at the head of the rapids. It is designed to furnish power for a pulp mill the foot. The total head obtained by this plant will be 55 feet. Fig. 4 shows the plan ıe proposed development. Water is to be conducted from the dam by a canal extend- on the left bank for a distance of about 5,000 feet to high bluffs 100 feet from the river . The power house will be on the river bank immediately below. The dam will back

the water nearly to Brunett Falls, 9½ miles above, and will cover the Colton and Chevalk rapids.

Brunett Falls.—One of the best powers on Chippewa River, and one most cheaply deve oped, is found at Brunett Falls (Pl. III, *B*), located in sec. 18, T. 31 N., R. 6 W. It belon

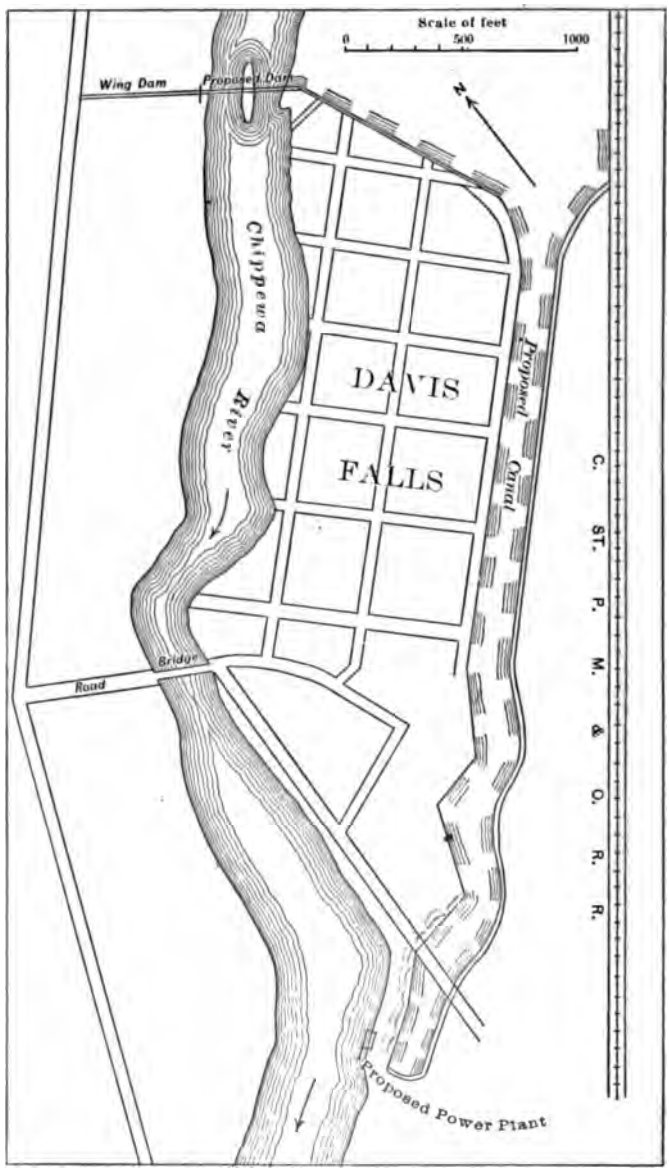


FIG. 4.—Plan of proposed water-power development at Jim Falls (Davis Falls).

to Cornell University, which also owns the adjacent land as well as the water rights. Th best location for the dam would be about 650 feet above the foot of the rapids, where 35-foot dam would back the water up to the rapids at Holcombe, 5½ miles above. Th river at the dam site is narrow (70 or 80 feet), while the banks are high, granite ledge

ere would create a large reservoir. It is stated that the plans contemplate a dam long. A steel wagon bridge has recently been built across the river immediately e dam site.

nbe dam.—The next power is at Holcombe, about 3 miles below the mouth of Jump here the Chippewa Falls Lumber and Boom Company maintains a timber dam, with f about 17 feet. This is the third dam that has been built here, the others having hed out by freshets. As the lumber interests are fast declining, the present dam is owed to decay. For power purposes it should be replaced by a more substantial . The river here has a rock bottom, with rather low clay sides, but an 18-foot ld be constructed on the site of the present structure, which, together with a lam at the foot of the rapids just below (sometimes called Little Falls), would about all the head at this point and would not flood any more valuable lands above. ld back the water above Deertail Creek and furnish considerable storage.

of Flambeau.—Of the 14 feet of descent in Chippewa River between Holcombe mouth of the Flambeau 10 feet are concentrated in the first mile below the latter It is very likely that a dam on this reach would easily develop 15 feet of head. vorthy of note that all the water powers on Chippewa River thus far described ed by one or more railroads. Because of their availability many of the above re likely to be developed in the near future. Their importance is emphasized ollowing statement: Of the 244 feet descent in the Chippewa between Chippewa d the mouth of the Flambeau, 116 feet are concentrated in 5 falls and rapids. ding of 10 dams would economically develop a total of 213 feet head in this dis- 43 miles. When fully developed these powers will rival in importance the extensive nents on lower Fox River between Appleton and Green Bay.

BRANCHES AND UPPER WATERS.

raphy and drainage.—The following statements in regard to the water powers of ippewa River, not being based on a hydrographic survey, are necessarily incom- Statements concerning profile, etc., are based on the survey and maps of this ade in 1880 by United States engineers in connection with the reservoir surveys. and drainage area data are shown in the following table:

Length and drainage area of the upper tributaries of Chippewa River.

River.	Length (map measure).	Drainage area.
	Miles.	*Sq. miles.*
nch of Chippewa	35	480
nch of Chippewa	60	278
illes	20	176
1	155	1,983
	65	721
	65	458
e	65	899
r	95	1,957

16½ miles between the mouth of the Flambeau and Bruce Chippewa River descends foot per mile, but in the 38½ miles between Bruce and the confluence of East t branches of the Chippewa, in sec. 2, T. 39 N., R. 6 W., the river descends 216 average of 5.6 feet per mile. This steep gradient is certain to produce many wers. This reach is, however, devoid of railroads except a few logging roads. hese undeveloped powers, called Belills Falls, is located in sec. 26, T. 38 N., Its owner, the John Arpin Lumber Company, reports that this power is capable

of producing a head of about 30 feet. It is near Radison, on the Chicago, St. Paul, Minneapolis and Omaha Railway.

East Branch of Chippewa.—Three important rapids occur in East Branch of Chippewa River. Between Little Chief Lake and the confluence of East and West branches, a distance of 2.7 miles, there is a descent of 43 feet. Between these points there is a series of rapids, "the bed of the river being literally paved with bowlders. The banks are from 10 to 20 feet high and the drift a reddish clay." These are known as the Goose Eye rapids. Two or three dams could develop a head of about 40 feet.

Above Hunters Lake, in secs. 22 and 23, T. 40 N., R 5 E., occur the Snaptail rapids, with an aggregate descent of 43.6 feet.

Cedar rapids, the last of importance on this branch, with a descent of 16 feet, are located in sec. 9, T. 40 N., R. 4 W., and in the 2 miles above. The total descent between Blaisdell and Bear lakes is about 58 feet, all in a distance of 7½ miles. Between Bear and Little Chief lakes the banks vary from 4 to 50 feet in height. A logging dam has been maintained at the head of the rapids, in sec. 26, T. 41 N., R. 4 W., which had a height of 10 feet. Measurements made here by United States engineers on June 20 and July 12, 1879, with the river respectively 0.6 and 2.1 feet above low-water mark, showed a discharge of 381 and 472 second-feet. The river at this point is 153 feet wide.

West Branch of Chippewa.—West Branch of the Chippewa River has a drainage area of 480 square miles, or 200 square miles more than East Branch, but its descent is considerably less rapid. The river has its source in several large lakes at about 1,380 feet above sea level. The first undeveloped power is located about 1½ miles above the confluence of the two branches, in sec. 34, T. 40 N., R. 6 W., where the hills approach within 900 feet. The river at this point has a width of 121 feet, and here United States engineers made surveys for a dam with a head of 25½ feet, which gave a very large reservoir area. A 15-foot head could probably be obtained at reasonable expense. Four measurements made by United States engineers on August 6, 1879, at a stage only 0.2 foot above low water gave a mean discharge of 360 second-feet, or 0.75 second-feet per square mile of drainage area. This large low-water run-off is double that estimated for this drainage area. The excess may be explained by the steadying action of the large lakes near the headwaters of this river.

In the 10 miles between Moose and Pakwawang lakes West Branch descends 71.6 feet, including a series of rapids with sluggish water between. The banks are generally from 20 to 30 feet high, with clay soil.[a]

Court Oreilles River.—Court Oreilles River has its source at an elevation of 1,287 feet in a lake of the same name. The group of lakes forming its headwaters have a total area of about 16 square miles. A dam at this outlet would need to have a length of 260 feet to secure a head of 5 feet, and would store a supply sufficient to deliver 255 second-feet for ninety days at times of low water. The river is from 50 to 60 feet wide, and in the first 3 miles of its course is sluggish. Thence to its mouth it furnishes a series of rapids, with still reaches between. The most important rapids, known as the Court Oreilles, are situated within 3 miles from the mouth of the river, which at this point flows over ledges of the pre-Cambrian rocks. The river is crossed at its middle point by the Chicago, St. Paul, Minneapolis and Omaha Railway, where the water surface has an elevation of 1,240 feet. This shows a descent of 47 feet in 10 miles between this point and the lake. The lower half of the river is reached by the above railway. Unlike either East Branch, West Branch, or any other neighboring branches of the Chippewa, Court Oreilles River drains a region with a very open sandy soil. A measurement made by United States engineers, October 25, 1879, at a stage 0.3 foot above low water, showed a discharge at the mouth of Lake Court Oreilles of only 28 second-feet from a drainage area of 114 square miles. It seems likely that, because of the character of the soil, part of the run-off escapes underground to the west into Namekagon River.

[a] Rept. Chief Eng. U. S. Army, 1880, p. 1562.

s.—Because of their present isolation from railroads, the chief use of dams n maintained on the upper headwaters of Chippewa River would lie in their eservoirs to improve the powers below. Their location is shown in the :

Dams on upper waters of Chippewa River.[a]

Location.	Dimensions.[b]		Reservoir capacity.
	Height.	Length.	
ver:	*Feet.*	*Feet.*	*Cubic feet.*
c. 28, T. 32 N., R. 6 W	21	625	133,333,000
'. 33 N., R. 8 W	9	.....	153,331,000
'. 32 N., R. 6 W	17	.....	334,536,000
ı:			
V. ¼ sec. 32, T. 42 N., R. 5 W	8	123	.....
. 42 N., R. 5 W	*20	*300	.....
:. ¼ sec. 14, T. 41 N., R. 6 W	7	347	430,000,000
tegama Lake, NW. ¼ NW. ¼ sec. 32, T. 40 N., R. 6 W.	8	108	.....
tiver, NE. ¼ NE. ¼ sec. 26, T. 40 N., R. 7 W	6	142	.....
, NW. ¼ SE. ¼ sec. 26, T. 41 N., R. 4 W	10	564	300,000,000
River:			
'. 35 N., R. 6 W	*18	*800	.....
36 N., R. 5 W	*18	*400	.....
'. 38 N., R. 4 W	*12	*250	.....
38 N., R. 4 W	*15	*250	.....
'r, sec. 17, T. 38 N., R. 5 W	*15	*325	.....
sec. 16, T. 42 N., R. 4 W	*20	*300	.....

os. 1-4 and 6-9, United States engineers; 5 and 10-15, Chippewa Lumber and Boom
ıarked with an asterisk (*) were estimated by the owner. The Chippewa Lumber and

TRIBUTARIES OF CHIPPEWA RIVER.

FLAMBEAU RIVER.

! water powers.—In size of drainage area Flambeau River ranks first among of the Chippewa. Indeed, because of its central location in the drainage properly be regarded as the prolongation of the main stream itself. Regard- ıowever, its water power must, in large part, continue for some time unused, orested location and its lack of railroad facilities. The settling of this area justify the extension of present railroads and the building of new ones. 'r is crossed near its mouth (at Ladysmith) by the Minneapolis, St. Paul and Railway, near its center (at Park Falls) by the Wisconsin Central Railway, 'r headwaters by the Chicago and Northwestern Railway. Between Park smith is a reach of 70 miles unserved by railroad, and yet with no point at a e than 15 miles from the present railroads. It is significant that the two ısportation facilities, Ladysmith and Park Falls, have established large paper ınd other manufactories. The unusually steady flow, the soft water, and the nost unlimited quantities of pulp wood should make this river a center of the industry. Transportation alone is lacking.

iver has its source in the largest number of lakes and connecting swamps ıt aggregate storage capacity of any river in the State. This storage capacity sed in many cases by lumbering dams built at the lake outlets, but as yet ities for the storing of surplus waters remain unimproved. These lakes lie ɔortion of the State, at elevations varying from 1,560 to 1,650 feet or more The levels show that the river descends 570 feet in a distance of 150 miles,

or about 3.8 feet per mile. A large part of this fall is known to be concentrated at numerous falls and rapids. In the 19 miles between the mouth of the river and Ladysmith the descent is 42 feet. A company has recently been formed to construct a dam with a head of 20 feet at a point 6 miles below Ladysmith, in sec. 18, T. 34 N., R. 6 W., and the work of construction is already begun. The next developed power above the mouth is found at Ladysmith, where a timber dam 350 feet long develops a head of 16 feet. This power is used to run a paper and pulp mill and also for the manufacture of wooden ware.

There are no developed powers on Flambeau River for 70 miles above Ladysmith, but a fall of 353 feet in this distance insures many undeveloped powers. Two of these, Little Falls and Big Falls, are of special importance. The former is located in the NW. ¼ sec. 21, T. 35 N., R. 5 W., and is owned by A. J. McGilvary and B. D. Viles, of Chippewa Falls. A 15-foot dam at the head of the first rapids would give a head of about 25 feet at the foot of the rapids a short distance below. Big Falls, owned by the John Heim Company, of Tony, Wis., is located 6 miles above Little Falls, in sec. 35, T. 36 N., R. 5 W. There is a descent of 25 feet here in a short distance, concentrated in three pitches. A view of one is shown in Pl. V, A. No accurate survey has been made of either fall, but the owner of Big Falls estimates that a 25-foot dam at the head of the rapids and a canal about five-eighths of a mile to the end of the rapids would give a 60-foot head. Both falls occur over ledges of pre-Cambrian crystalline rock.

At Park Falls the Flambeau Paper Company has constructed two dams; one, half a mile above the railroad crossing, in sec. 13, T. 40 N., R. 1 W., and one about a mile below, in sec. 25, T. 40 N., R. 1 W. Each dam furnishes an average head of 16 feet. The upper plant has installed 13 turbines, rated at 1,300 horsepower, while at the lower plant about 1,100 horsepower has been installed.

There are other rapids in secs. 28, 32, and 33, T. 41 N., R. 1 E., and levels taken by United States engineers showed a fall here of 24 feet in 2 miles. Again, in secs. 3 and 4, T. 41 N., R. 2 E., below the junction of Turtle and Flambeau rivers, is a similar fall of 25 feet. Above this point the river is much smaller and has lower gradient, though bowlder rapids are of frequent occurrence.

The lack of railroad transportation on this watershed will postpone the utilization of its many large water powers until the region is more thickly settled and better served by railroads.

Profile.—No Government surveys have been made in the 46 miles above Big Falls, so that reliable data regarding water powers along this portion of the river are almost entirely lacking. Above Park Falls United States engineers have run levels in connection with the reservoir surveys, thus furnishing valuable hypsometric data. Information concerning the river profile from mouth to headwaters, with the exception noted above, is fairly complete, and is summarized in the following table:

Profile of Flambeau River from its mouth to Boulder Lake.[a]

No.	Station.	Distance.		Elevation above sea level.	Descent between points.	
		From mouth.	Between points.		Total.	Per mile.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
1	Mouth of river	0.0	.....	1,050.0	.....	.....
2	SW. ¼ sec. 34, T. 34 N., R. 7 W.	7.0	7.0	1,064.0	14.0	2.0
3	Duncomb rapids, NW. ¼ sec. 23, T. 34 N., R. 7 W.	11.0	4.0	1,070.0	6.0	1.5
4	New dam, foot of rapids	15.0	4.0	1,081.0	11.0	2.7
5	SW. ¼ sec. 1, T. 34 N., R. 6 W.	15.75	.75	1,088.4	7.4	10.0
6	Ladysmith, below dam	24.25	8.5	1,099.0	10.6	1.25

[a] Authority: No. 1-26, U. S. Geol. Survey; 27-30, U. S. engineers. Because of an error in the assumed elevation of the initial bench mark, 15 feet is added to the U. S. engineer elevation to correct to sea-level datum.

A. LOWER PITCH OF BIG FALLS, FLAMBEAU RIVER.

B. COPPER FALLS, BAD RIVER.

ofile of Flambeau River from its mouth to Boulder Lake—Continued.

Station.	Distance.		Elevation above sea level.	Descent between points.	
	From mouth.	Between points.		Total	Per mile.
	Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
h, above dam	24.25	0.0	1,115.3	16.3	.....
. 25, T. 35 N., R. 6 W	28.0	3.75	1,115.4	.1	.....
ls, foot of	32.0	4.0	1,131.4	16.0	4.0
ls, head of (sec. 21, T. 35 N., R. 5 W.)	32.8	.8	1,147.4	16.0	20.0
15, T. 35 N., R. 5 W	36.8	4.0	1,166.7	19.3	4.8
foot of (NW. ¼ sec. 2, T. 35 N., R. 5 W.)	40.3	3.5	1,177.0	10.3	[a] 3.0
. 8, T. 39 N., R. 1 W	86.2	45.9	1,421.8	244.8	5.3
sec. 33, T. 40 N., R. 1 W	91.2	5.0	1,429.6	7.8	1.5
40 N., R. 1 W., west line of	94.2	3.0	1,438.0	8.4	2.8
n, sec. 25, T. 40 N., R. 1 W., west line of	95.0	54.7	1,454.0+	.....	.....
m	95.0	0.0	1,470.0+	.....	.....
s railroad bridge, west line sec. 24, T. 40 W	96.6	1.6	1,470.0	.....	.....
l race upper dam, Park Falls	98.3	.5	1,466.8	2.8	5.6
per dam, Park Falls	98.5	.2	1,481.0	14.2	.....
r, upper dam	104.3	5.8	1,482.5	1.5	.2
. 28, T. 41 N., R. 1 E	107.1	2.8	1,499.2	16.7	6.0
41 N., R. 1 E., W. ¼ stake	112.5	5.4	1,510.8	11.6	2.0
41 N., R. 2 E., W. ¼ stake	115.8	3.3	1,516.0	6.2	1.8
ver, mouth	119.0	3.2	1,541.4	25.4	7.6
sh River, junction of Bear Creek	134.0	15.0	1,568.0	26.6	1.8
, mouth of (sec. 8, T. 42 N., R. 5 E.)	146.0	12.0	1,587.0	19.0	1.6
ke, inlet of	153.5	7.5	1,592.0	5.0	.66
ake	163.0	9.5	1,625.0	33.0	3.5

d run-off.—Like all the northern rivers of the State the minimum flow of ver occurs in severe midwinter weather, or during very dry summers in the ly and August. At present there are not sufficient discharge data covering the river is frozen to construct an accurate rating curve for such periods. e extensive forest and the numerous lakes and swamps, an ordinary flow of t per square mile of drainage area would seem conservative. By the proper present dams at the headwaters it is likely that this discharge could be con- eased.

y, 1903, the United States Geological Survey established an observing station nith dam, and has taken daily gage readings since. Discharge measurements urrent meters and are being continued so that in time an accurate estimate of charge will be available. The following tables give such daily observations:

discharge measurements, and computations as have become available since the establishment of the station, and also a record of rainfall for the corresponding period:

Discharge measurements of Flambeau River near Ladysmith, Wis., for 1903, 1904, and 1905.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height	Discharge.
		Feet.	*Square feet.*	*Feet per second.*	*Feet.*	*Second-feet.*
1903.						
February 13[a]	L. R. Stockman	325	472	1.64	16.20	773
March 19[b]	do	366	1,871	1.77	18.95	3,312
April 8	do	349	1,330	2.80	17.40	3,727
May 6	do	361	1,927	3.70	18.97	7,113
June 16	do	342	703	1.91	16.00	1,345
July 11	do	342	1,430	2.95	18.10	4,222
August 21	do	342	995	2.69	16.85	2,681
September 10	E. C. Murphy	364	1,579	3.36	18.05	5,303
October 23	L. R. Stockman	348	1,271	3.07	17.21	3,880
1904.						
May 16	E. Johnson, jr	350	1,333	3.15	17.88	4,203
June 3	do	350	1,448	2.99	17.45	4,321
August 29	do	349	733	2.07	16.06	1,517
September 20	do	343	702	2.21	16.01	1,554
October 12	F. W. Hanna	364	1,653	3.37	18.58	5,568
1905.						
April 8	S. K. Clapp	129	1,537	3.49	18.27	5,367
May 23	do	357	1,292	2.69	17.60	3,474
June 14	M. S. Brennan	354	1,232	2.67	17.35	3,288
July 12	do	353	1,015	2.54	16.80	2,576
August 12	do	345	623	1.84	15.66	1,144
September 23	F. W. Hanna	353	1,404	3.02	17.75	4,236

[a] Frozen. [b] Log jam below.

Mean daily gage height, in feet, of Flambeau River near Ladysmith, Wis., February 15, 1903, to December 31, 1905.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1903.											
1	.....	16.15	17.00	18.30	19.80	15.65	.....	17.00	17.20	16.00	15.90
2	.....	16.60	16.80	18.40	19.65	16.15	.....	16.70	17.30	16.25	15.75
3	.....	16.50	16.90	18.60	18.95	17.25	.....	16.80	17.60	15.85	15.95
4	.....	16.10	16.90	19.05	18.60	18.10	.....	16.30	19.65	15.85	15.60
5	.....	16.30	17.05	19.10	18.10	18.90	.....	16.80	19.70	15.85	15.80
6	.....	16.50	16.40	19.10	17.55	19.05	.....	16.90	19.35	15.85	15.80
7	.....	16.60	16.90	19.10	17.55	19.20	.....	16.90	19.25	15.90	16.95
8	.....	16.10	17.45	18.80	17.30	18.85	.....	17.30	19.25	15.65	15.80
9	.....	16.50	17.35	18.70	16.95	18.70	.....	18.20	19.30	15.70	14.70
10	.....	16.50	17.25	17.95	16.60	18.60	18.20	18.20	19.35	15.85	16.50
11	.....	16.05	17.25	18.25	16.75	18.75	18.00	18.00	18.95	16.00	16.35
12	.....	16.45	17.30	18.80	16.80	18.55	17.90	18.40	18.65	15.85	16.30
13	.....	16.35	17.25	19.55	16.30	18.30	17.80	19.00	18.45	15.85	16.50
14	.....	16.35	17.50	19.80	16.15	17.85	17.70	19.80	18.25	15.80	16.45
15	16.00	16.60	17.40	19.65	16.35	17.70	17.50	20.40	17.90	15.80	16.55
16	16.10	16.15	17.20	19.55	16.50	17.65	17.30	20.50	17.85	15.75	16.35
17	16.05	16.20	16.95	19.40	16.05	17.60	17.30	20.50	17.80	15.80	16.40
18	16.00	16.30	17.00	19.45	16.05	17.35	17.20	20.30	17.50	15.00	16.70
19	15.90	18.25	16.90	19.05	15.85	17.35	17.00	20.00	17.35	15.50	16.60

ean daily gage height, in feet, of Flambeau River near Ladysmith, Wis., February 15, 1903, to December 31, 1905—Continued.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1903.											
.....	16.00	20.35	16.85	19.20	15.80	17.20	17.00	19.70	17.25	15.50	16.67
.....	15.90	19.30	16.90	19.25	15.85	17.15	17.10	19.30	17.25	15.45	16.67
.....	16.05	18.50	16.65	18.85	15.95	16.70	16.90	18.90	17.15	15.25	16.67
.....	16.00	18.45	16.65	19.15	15.65	16.70	16.70	18.50	17.05	15.40	16.66
.....	16.25	17.30	17.30	18.90	15.90	16.70	16.80	18.20	17.00	15.65	17.00
.....	16.00	17.60	17.30	19.00	15.60	16.80	17.10	18.00	16.80	15.45	16.69
.....	15.95	17.25	17.25	19.55	15.85	(a)	16.80	17.70	17.00	15.55	16.66
.....	16.40	17.00	17.15	20.60	15.60	(a)	17.00	17.85	16.80	15.85	16.50
.....	16.25	17.10	17.20	21.45	15.70	(a)	16.90	17.50	16.55	15.80	16.10
.....	.....	17.00	17.40	21.45	15.95	(a)	16.80	17.30	16.65	15.80	16.80
.....	.....	16.75	18.45	21.20	15.80	(a)	16.70	17.20	16.05	15.85	16.80
.....	.....	16.60	.....	21.45	.....	(a)	16.80	.....	16.20	.....	16.70

Day.	Jan.[b]	Feb.[c]	Mar.[b]	Apr.[c]	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.[d]
1904.												
.....	16.75	16.75	17.00	16.90	18.70	17.50	17.58	15.15	16.25	(e)	17.25	15.65
.....	16.95	16.75	17.05	17.20	18.55	17.40	17.77	15.40	16.30	(e)	17.30	15.05
.....	16.75	16.10	17.00	16.80	18.60	17.42	17.70	(f)	16.38	(e)	17.20	15.95
.....	16.85	16.80	17.05	16.90	18.35	17.43	19.90	(f)	17.78	(e)	16.90	14.50
.....	17.00	16.90	17.15	16.85	18.45	18.00	18.82	15.60	17.65	16.05	16.70	15.15
.....	16.50	16.70	16.95	16.80	18.60	18.02	18.88	15.72	17.20	16.05	16.80	15.30
.....	16.50	16.80	16.90	17.10	18.60	18.25	18.75	15.13	17.28	16.10	16.30	14.87
.....	16.65	16.75	17.15	17.25	18.85	18.27	18.75	15.40	17.30	16.10	16.20	15.78
.....	16.65	16.75	16.90	17.05	19.20	17.90	18.05	15.75	17.03	17.05	16.17	15.57
.....	16.70	16.65	17.50	17.00	19.15	17.22	17.95	15.92	16.00	18.70	16.15	15.55
.....	16.60	16.70	17.40	17.10	18.90	17.10	17.70	15.85	16.40	18.65	16.05	15.25
.....	16.55	16.95	17.05	17.10	18.80	17.25	17.25	16.00	16.32	18.60	15.55	15.77
.....	16.50	17.00	17.30	17.15	18.35	17.15	16.40	15.90	16.45	18.50	15.60	15.55
.....	16.70	16.70	17.20	17.05	18.15	17.12	16.30	15.90	16.30	18.43	15.45	15.30
.....	16.70	16.90	17.20	17.25	18.01	16.60	16.12	15.85	16.15	18.30	15.82	15.35
.....	16.75	16.95	17.00	17.20	17.95	16.55	16.15	16.02	16.05	17.85	15.28	15.45
.....	16.60	16.55	17.15	17.10	18.01	16.35	16.03	15.90	16.05	17.20	15.55	15.35
.....	16.60	17.10	17.20	17.05	18.01	16.25	16.00	15.85	16.13	16.95	15.72	15.30
.....	16.65	16.95	17.15	17.00	18.03	16.32	15.60	15.95	16.15	17.15	15.70	15.50
.....	16.30	16.95	17.05	16.85	17.05	15.95	15.80	15.75	16.00	17.25	15.60	15.57
.....	16.75	17.55	17.05	16.85	17.03	15.88	15.95	16.00	16.00	17.60	15.45	15.70
.....	16.75	16.90	17.15	16.65	17.01	16.15	15.85	16.20	15.90	17.80	15.82	15.72
.....	16.75	17.00	16.85	17.20	17.04	15.95	15.80	16.35	15.95	17.75	15.27	15.68
.....	16.65	16.60	17.15	17.20	17.06	16.35	15.70	16.45	15.95	17.75	15.55	15.60
.....	16.70	17.00	16.95	18.00	18.40	16.55	15.85	16.65	16.40	17.85	15.72	15.65
.....	16.70	16.90	16.95	18.40	19.00	16.70	16.15	16.45	16.40	17.75	15.70	15.70
.....	16.45	17.00	16.95	18.45	19.40	16.95	16.76	16.45	16.40	17.65	15.55	16.10
.....	16.65	16.95	17.15	18.50	19.30	17.05	16.75	16.20	16.45	17.55	15.40	15.75
.....	16.60	16.95	17.05	18.50	18.80	17.05	15.70	16.10	16.40	17.65	14.95	15.80
.....	16.75	.....	16.45	18.90	18.40	17.20	15.25	16.27	16.45	17.70	15.55	16.30
.....	16.65	.....	17.20	.....	17.80	.....	15.55	16.15	.....	17.22	.....	16.40

[a] Chain gage stolen.
[b] Frozen from January 1 to March 30, when ice begins to break. Ice varied from 6 to 18 inches in ickness.
[c] Ice conditions March 31 to about April 10.
[f] Ice conditions during December.
[e] Weight gone.
[d] Key lost; no gage height taken on August 3 and 4.

Mean daily gage height, in feet, of Flambeau River near Ladysmith, Wis., etc.—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1905.												
1	(a)			18.80	16.8	17.40	17.70	15.80	16.90	16.55	16.40	16.15
2				18.40	16.8	16.25	17.60	15.90	16.60	16.55	16.25	15.90
3				19.00	16.8	16.40	17.50	15.80	16.90	16.35	16.15	15.85
4		16.4	16.80	19.20	17.0	16.80	17.60	15.70	17.00	16.25	16.05	16.20
5				18.90	17.3	17.80	18.60	15.75	17.00	16.20	16.20	15.95
6				18.40	17.6	18.70	19.00	15.35	16.90	16.15	16.15	16.10
7	16.3			18.40	17.6	19.60	19.20	15.35	16.60	15.80	16.20	16.45
8				18.20	17.4	19.30	18.80	15.30	16.70	15.95	16.15	16.15
9				18.10	17.1	18.90	18.50	15.50	16.50	15.80	16.05	16.25
10				17.80	17.4	18.70	18.20	15.30	16.40	15.95	15.95	16.25
11		16.5	16.00	17.40	17.5	18.60	17.40	15.40	16.20	15.55	16.05	15.90
12				17.20	17.8	18.60	17.00	15.55	16.20	16.20	16.30	15.80
13				17.20	17.8	17.60	17.00	15.40	16.25	16.15	16.30	15.90
14	16.6			18.20	18.0	17.50	17.00	15.32	16.25	16.10	16.20	15.70
15				18.10	18.3	17.60	16.70	15.45	16.45	16.40	16.10	15.70
16				17.60	18.2	17.70	16.60	15.60	16.80	16.75	16.25	16.20
17				17.20	18.4	18.00	16.35	15.55	17.10	16.75	16.05	16.40
18		16.7	16.90	16.55	18.6	19.70	16.35	15.90	17.05	17.00	15.90	15.70
19				16.55	18.6	19.60	16.40	16.80	17.70	17.65	15.90	15.95
20				16.45	18.4	19.40	16.15	16.90	17.80	17.20	15.85	15.45
21	16.7			16.55	18.0	19.10	16.10	17.10	18.20	17.65	15.90	15.65
22				17.00	18.0	18.90	16.20	16.90	18.40	17.35	15.70	15.60
23				16.30	17.4	18.60	15.90	16.60	17.80	17.45	15.75	15.65
24			16.80	16.35	18.0	18.40	15.50	16.45	17.60	17.30	15.60	15.70
25		16.6	16.45	16.15	17.6	18.00	15.90	16.80	17.30	17.10	16.00	16.75
26			16.35	16.05	17.4	18.00	15.75	16.35	17.20	16.85	16.60	16.10
27			16.25	17.40	17.2	18.00	15.80	16.25	16.80	16.85	16.10	15.60
28	16.6		17.10	17.40	18.0	17.70	15.80	16.80	16.80	16.80	16.60	16.00
29			17.90	17.00	17.8	17.70	15.75	17.00	16.70	16.70	16.15	15.90
30			18.20	16.80	17.6	17.70	15.70	17.20	16.20	16.55	15.90	16.15
31			18.60		17.4		15.55	17.00		16.30		16.10

[a] River frozen entirely across January 1 to March 23. March 11-23 there was water on the ice. Gage heights are to water surface in a hole in the ice. The following comparative readings were also made:

Date.	Water surface.	Top of ice.	Thickness.
	Feet.	*Feet.*	*Feet.*
January 7	16.3	16.4	0.7
January 14	16.6	16.8	1.3
January 21	16.7	16.9	1.4
January 28	16.6	16.9	1.5
February 4	16.4	16.9	1.7
February 11	16.5	16.9	1.7
February 18	16.7	17.1	2.0
February 25	16.6	16.9	1.8
March 4	16.8	17.8	1.8

ting table for Flambeau River near Ladysmith, Wis., from March 19, 1903, to December 1, 1903. [a]

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
15.0	530	16.3	1,765	17.6	4,280	18.8	6,920
15.1	555	16.4	1,925	17.7	4,500	18.9	7,140
15.2	600	16.5	2,085	17.8	4,720	19.0	7,360
15.3	665	16.6	2,245	17.9	4,940	19.2	7,800
15.4	745	16.7	2,405	18.0	5,160	19.4	8,240
15.5	825	16.8	2,575	18.1	5,380	19.6	8,680
15.6	915	16.9	2,755	18.2	5,600	19.8	9,120
15.7	1,010	17.0	2,960	18.3	5,820	20.0	9,560
15.8	1,110	17.1	3,180	18.4	6,040	20.2	10,000
15.9	1,220	17.2	3,400	18.5	6,260	20.4	10,440
16.0	1,340	17.3	3,620	18.6	6,480	20.6	10,880
16.1	1,465	17.4	3,840	18.7	6,700	21.0	11,760
16.2	1,610	17.5	4,060				

[a] Made from measurements between gage heights 16 and 18.95 feet. Curve above and below these ints is approximate. To be used only for open river.

ting table for Flambeau River near Ladysmith, Wis., from January 1, 1904, to December 31, 1904.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
15.0	567	16.0	1,399	17.0	2,841	18.4	5,291
15.1	596	16.1	1,542	17.1	2,990	18.6	5,704
15.2	637	16.2	1,686	17.2	3,143	18.8	6,120
15.3	690	16.3	1,830	17.3	3,300	19.0	6,539
15.4	755	16.4	1,974	17.4	3,461	19.2	6,959
15.5	832	16.5	2,118	17.5	3,626	19.4	7,379
15.6	921	16.6	2,262	17.6	3,795	19.6	7,799
15.7	1,022	16.7	2,406	17.8	4,145	19.8	8,219
15.8	1,135	16.8	2,550	18.0	4,511	20.0	8,639
15.9	1,260	16.9	2,695	18.2	4,893		

Rating table for Flambeau River near Ladysmith, Wis., from January 1 to December 31, 1905.

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge
Feet.	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*	*Feet.*	*Second-feet.*
15.00	600	16.20	1,735	17.40	3,510	18.50	5,770
15.10	670	16.30	1,855	17.50	3,700	18.60	5,980
15.20	745	16.40	1,980	17.60	3,890	18.70	6,190
15.30	825	16.50	2,110	17.70	4,090	18.80	6,400
15.40	910	16.60	2,245	17.80	4,300	18.90	6,610
15.50	1,000	16.70	2,385	17.90	4,510	19.00	6,820
15.60	1,090	16.80	2,530	18.00	4,720	19.20	7,240
15.70	1,185	16.90	2,680	18.10	4,930	19.40	7,680
15.80	1,285	17.00	2,835	18.20	5,140	19.60	8,120
15.90	1,390	17.10	2,995	18.30	5,350	19.80	8,560
16.00	1,500	17.20	3,160	18.40	5,560	20.00	9,000
16.10	1,615	17.30	3,330				

The above table is applicable only for open-channel conditions. It is based on discharge measurements made during 1903–1905. It is not very well defined.

Estimated monthly discharge of Flambeau River near Ladysmith, Wis., for 1903, 1904, and 1905.

[Drainage area, 2,120 square miles.]

Date.	Discharge.			Run-off.		Rainfall.[a]
	Maximum.	Minimum.	Mean.	Per square mile.	Depth.	
1903.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Inches.*	*Inches.*
January						0.46
February [b]			860	0.41	0.21	.98
March	10,330	833	2,736	1.29	1.49	2.57
April	6,150	1,925	3,266	1.54	1.72	3.09
May	12,750	5,050	8,187	3.86	4.45	6.04
June	9,120	915	2,749	1.30	1.45	1.64
July [c]			4,598	2.17	2.02	8.70
August [d]			3,431	1.62	1.33	5.66
September	10,660	1,765	5,777	2.72	3.03	8.53
October	8,900	1,400	4,807	2.27	2.62	3.23
November	1,685	530	1,054	.50	.56	.94
December						.57
The year						43.23
1904.						
January						.43
February						1.11
March						1.76
April [e]	6,339	2,334	3,389	1.60	1.78	1.77
May	7,379	2,856	5,183	2.44	2.81	4.64
June	5,034	1,234	2,890	1.36	1.52	5.64
July	8,429	662	2,834	1.34	1.54	2.14
August [f]	2,334	607	1,336	.630	.726	5.01
September	4,109	1,260	2,056	.970	1.08	4.70
October [f]	5,912	1,470	3,517	1.66	1.91	5.61
November	3,300	555	1,416	.668	.745	.19
December [e]	1,974	390	951	.449	.518	2.30
The year						35.43
1905. [g]						
March 24-31		5,980	1,795	3,384	1.60	.476
April		7,240	1,558	3,867	1.82	2.03
May		5,980	2,530	4,090	1.93	2.22
June		8,340	1,795	5,223	2.46	2.74
July		7,240	1,000	2,950	1.39	1.60
August		3,160	825	1,669	.787	.907
September		5,560	1,735	2,839	1.34	1.50
October		3,990	1,045	2,305	1.09	1.26
November		2,245	1,090	1,616	.762	.850
December		2,045	955	1,449	.683	.787

[a] Rainfall for 1903 is the average of the recorded rainfall at Butternut, Medford, and Eau Claire; that for 1904 omits Eau Claire and adds Prentice and Minocqua.
[b] February 15 to 28, inclusive.
[c] July 1 to 25, inclusive.
[d] August 10 to 31, inclusive.
[e] Estimates April and December made as if open channel.
[f] Discharge estimated for August 3 and 4 and October 1 to 4.
[g] No estimate for ice period.

butaries of Flambeau River.—Dore Flambeau River, the south branch of the Flambeau, ıt an elevation of 1,582 feet above the sea, in a group of a dozen lakes, the largest being Lake. Its total drainage area is 742 square miles. After a very rapid course of about les it joins the main stream in sec. 31, T. 37 N., R. 3 W. In the 27 miles between Long and Fifield the river descends 146 feet, or 5.4 feet to the mile. Its gradient below d has not been determined, but it is known to have many important falls and rapids. of the largest of these, located in sec. 33, T. 37 N., R. 3 W., has a total fall of 35 feet. g to its lakes and swamps this river has a much more uniform flow than any of the ıewa tributaries farther south. Dams are maintained by the Chippewa River Improve- Company at the outlet of Long Lake and at Fifield. The same company maintains ıg dams on Elk River in sec. 11, T. 37 N., R. 2 W., and also in sec. 14, T. 37 N., R. 1 vith flowage of 1½ and 2½ square miles, respectively. These and other logging dams n this drainage area are listed in the following table:

Logging dams maintained on tributaries of Flambeau River.[a]

Location.	Dam.	
	Height.	Length.
Dore Flambeau River:	*Feet.*	*Feet.*
Sec. 7, T. 39 N., R. 1 E; sec. 24, T. 40 N., R. 1 E	16	350
Sec. 16, T. 38 N., R. 1 W	.....	.....
Secs. 23-26, T. 40 N., R. 3 E	15	400
Flambeau Lake, sec. 2, T. 40 N., R. 4 E	6	24
Manitowish River:		
Sec. 9, T. 42 N., R. 5 E	13	400
Sec. 24, T. 42 N., R. 6 E	17	300
Sec. 15, T. 42 N., R. 7 E	15	250
Elk River:		
Sec. 11, T. 37 N., R. 2 W	10	450
Sec. 14, T. 37 N., R. 1 W	10	.....
Trout River, sec. 14, T. 41 N., R. 6 E	4	.....
Bear Creek, sec. 2, T. 40 N., R. 4 E	.....	.....

uthority: Nos. 1 and 3, Wm. Irving, manager, Chippewa Lumber and Boom Co.; 4-8, Flambeau ›er Co.; 9, J. R. Davis Lumber Co.; 10 and 11, E. S. Shepard. Owners: Nos. 1, 3, and 5-7, Chippewa ›er and Boom Co.; 2, Lugar Lumber Co.; 4, Flambeau Lumber Co.; 8 and 9, Chippewa River ovement Co.

RED CEDAR RIVER.

ainage.—An area of 1,957 square miles in the extreme western part of Chippewa Valley ained by Red Cedar River (sometimes called the Menomonie), which, unlike the other tributaries of Chippewa River, does not reach the main stream until within a few miles its mouth. Except at its headwaters, Red Cedar River drains a region underlain by the ›rian sandstone. As a result, the greater part of the area has a sandy soil. A narrow ›f clayey loam, increasing in width southward, extends along the western limit of this The drainage area occupies the U-shaped region included between two terminal ines, one near the eastern and one near the western border, which unite at the upper vaters, giving rise to numerous lakes. Four of the largest of these have an area of about uare miles.

›file.—A study of the profile of Red Cedar River shows that its total descent in the 90 above its mouth is 470 feet, or 5.2 feet per mile. This gives opportunity for a large num- water powers. There are about 25 old logging dams on the river, besides about an equal

number of sawmills and flouring mills. The following table has been compiled surveys by competent engineers and from checked railroad levels:

Profile of Red Cedar River from its mouth to Red Cedar Lake.[a]

No.	Station.	Distance. From mouth.	Distance. Between points.	Elevation above sea level.	
		Miles.	*Miles.*	*Feet.*	
1	Mouth of river	0	.....	705.0	...
2	Dunnville	2.0	2.0	723.4	
	Downsville dam:				
3	Foot	7.8	5.8	739.0	
4	Crest	7.8	.0	758.2	
5	Irving	13.0	5.2	766.4	
	Menomonie dam:				
6	Foot	16.6	3.6	788.3	
7	Crest	16.6	.0	803.9	
8	"Omaha" bridge	18.9	2.3	806.7	
	Cedar rapids dam:				
9	Foot	23.4	4.5	823.3	
10	Crest	23.4	.0	842.0	
11	Hay River, mouth	30.2	6.8	859.3	
12	Colfax	35.0	4.8	895.0	
13	Cameron (2 miles west)	70.0	35.0	1,068.0	1
14	Railroad crossing	74.0	4.0	1,116.0	
15	Cedar Lake dam, sec. 22, T. 37 N., R. 10 W	90.0	16.0	1,191.0	
16	Dam in sec. 25, T. 37 N., R. 10 W	96.0	6.0	.....	...

[a] Authority: No. 1, Chicago, Milwaukee and St. Paul Railway; 2-11, O'Keef & Orbis Wis.; 12, Wisconsin Central Railway; 13, Minneapolis, St. Paul, and Sault Ste. Marie Rai 15, Chicago, St. Paul, Minneapolis and Omaha Railway.

A study of this table shows that Red Cedar River has a high gradient, averagin mile in the last 74 miles, with frequent concentrations of descent. No gagings have been made. Tributaries entering the river from the west flow through a soil, but the upper and eastern portions of the drainage area have a sandy-loan therefore likely that this river has a fairly uniform flow. The decline of the luml ests greatly increases the value of the Red Cedar River as a power producer.

Water powers and dams.—In the 30 miles below Hay River the Red Cedar de feet, and as this region borders the prairie region and is thickly settled, the six included will probably be developed to the full extent in the near future. T ment includes: (1) The construction of a dam at Dunnville, 2 miles above the r river, giving a head of 15.6 feet and an estimated 1,685 horsepower; (2) the r present dam at Downsville 4 feet, giving a total head of 23.2 feet and an esti horsepower; (3) the construction of a dam at Irving, with a total head of 21.9 fe estimated 2,260 horsepower; (4) the raising of the present dam at Menomonie 2 obtaining a total head of 18.4 feet and an estimated 1,800 horsepower; (5) the l new dam near the "Omaha" bridge, 2.8 miles above Menomonie, with a head of 1 an estimated 1,700 horsepower; (6) the raising of the present dam at Cedar rapi giving a total head of 40 feet and an estimated 3,800 horsepower.[a] Recently al owned by Knapp, Stout & Co., including many of the most valuable on the rive

[a] This statement is based on a careful survey for the owners made by O'Keef & Orbis engineers, of Appleton, Wis., and an estimated run-off of 0.461 second-foot per square mi

acquired by the Wisconsin Power Company, of Chicago, Ill. The location of 10 dams owned by this company is shown in the following table:

Dams on Red Cedar River owned by the Wisconsin Power Company.

Location.	Head.	Amount of flowage.	Authority.
	Feet.	*Cubic feet.*	
Sec. 25, T. 37 N., R. 10 W	14.0	1,674,000,000	U. S. engineers.
Sec. 2, T. 36 N., R. 10 W	7.0	405,000,000	Do.
Sec. 25, T. 36 N., R. 10 W	12.0		
Sec. 30, T. 36 N., R. 9 W	10.0	135,000,000	Do.
Sec. 29, T. 36 N., R. 9 W	10.0		
Sec. 13, T. 34 N., R. 10 W	12.0	40,500,000	Do.
Sec. 30, T. 33 N., R. 10 W	10.0	810,000,000	Do.
Downsville	19.0		J. W. Orbison.
Menomonie	15.5		Do
Cedar Falls	18.7		Do.

Railroads.—Between the mouth of Red Cedar River and Menomonie the Chicago, Milwaukee and St. Paul Railway closely parallels the river. In this stretch of 17 miles are situated the most important powers. Above Menomonie the drainage is crossed by the Chicago, Milwaukee and St. Paul, the Chicago, St. Paul, Minneapolis and Omaha, the Wisconsin Central, and the Minneapolis, St. Paul and Sault Ste. Marie railways.

EAU CLAIRE RIVER.

Ranked in order of its drainage area (900 square miles), Eau Claire River is third among the tributaries of the Chippewa. The greater part of this area is underlain by the Cambrian sandstone, and all except the upper headwaters drain a sandy-loam soil, as will be seen from Pl. II. Like most of the neighboring rivers, the Eau Claire has been an important lumbering stream, with many flooding dams. Very few water powers have been utilized. The first developed water power is about 500 feet from the mouth of the river, where a dam 300 feet long develops a head of 11 feet to run a linen mill, which uses only part of the power thus furnished. About 3,000 feet farther upstream is a second dam, with an average head of 13½ feet, owned by the Northwestern Lumber Company. An installation of turbines of 420 horsepower is reported. This is used in running a sawmill, a machine shop, and dynamos. The same company reports the three following lumbering dams on this river, but none of the resulting water power is utilized at the present time. In the NW. ¼ NE. ¼ sec. 14, T. 27 N., R. 9 W., is a dam with a 7-foot head, capable at ordinary low water of furnishing 210 theoretical horsepower. In the SW. ¼ NE. ¼ sec. 13, T. 27 N., R. 8 W., is a timber dam with a head of 8 feet, which could easily and cheaply be increased to 20 feet, thus producing at ordinary low water 540 theoretical horsepower. The third dam, with a present head of 20 feet, is reported in the SW. ¼ SW. ¼ sec. 5, T. 26 N., R. 6 W. This dam has not been used for many years and is much in need of repairs. There are many other opportunities for developing water powers on the Eau Claire River, as well as on its tributaries.

JUMP RIVER.

As its name would imply, Jump River is a very rapid stream, with numerous falls and rapids, making a descent of nearly 500 feet in its entire length of 65 miles. Its drainage area of 720 square miles is a long and narrow one, and with only a few unimportant exceptions is devoid of lakes and swamps. As a result the river has a very uneven flow as compared with the Flambeau, which stream it resembles in flowing through a valley whose soil is a clayey loam. The main portion of the Jump River valley has no railroads and is

sparsely settled. A branch of the Wisconsin Central is now being built across this drainage. The most important falls on the river, 35 feet in height, are in sec. 20, T. 34 N., R. 2 W., about 1 mile east of the junction of North and South forks, but there are numerous other dam sites of 15 to 20 foot head, which will doubtless be utilized when this section is settled.

YELLOW RIVER.

The drainage area of Yellow River is 460 square miles, distributed in a long, narrow valley. The lower half of the valley has a sandy soil, the upper part a clayey loam. While the gradient of Yellow River is not so great as that of its neighbor, Jump River, it has a rapid current. As in the case of other rivers in this region the only dams built were for logging purposes. The Miller dam is said to be the only one remaining. Three other dams, one at Colburn, one in sec. 7, T. 29 N., R. 5 W., and one at Cadott, have all been carried away by floods. The river is crossed by three railroads.

SMALLER TRIBUTARIES.

Chippewa River has a host of smaller tributaries, nearly all of which, because of their rapid currents and high, rocky banks, can be cheaply developed. Duncan Creek is a good example of what can be done with this class of tributaries. Although only 25 miles long, it has five dams with an aggregate head of 68 feet. Four gristmills, with a total turbine capacity of over 500 horsepower, take their power from this creek. Below the "Star mills," in the city of Chippewa Falls, is an unimproved power of 14-foot head; and immediately below this site is a dam with a 9-foot head, belonging to the Gatzian Shoe Manufacturing Company. The significant point regarding powers of this class is that they are cheaply improved and very widely distributed. The locations of some of them are shown in the following table:

Dams on smaller tributaries of Chippewa River.

Location.	Owner and use.	Head.	Installation.
		Feet.	*H. P.*
Arkansaw Creek, Arkansaw	Mills & Son, gristmill	12	25
Bass Creek, Afton	Wm. Denoger, flouring mill	9	40
Bear Creek, Durand	Durand roller mill, flour	18	73
Bridge Creek:			
Augusta	Dells Milling Co., flour	20	60
Sec. 18, T. 26, R. 6 W	F. P. Waddell	20	(a)
Duncan Creek:			
Chippewa Falls	Gotzian Shoe Co.	9	(b)
Do	Leinenkugel Brewing Co.	14	(a)
Do	Leinenkugel Co., flour	16	350
Sec. 31, T. 29 N., R. 8 W	Glen mills, flour	20	100
Sec. 24, T. 29 N., R. 9 W	G. W. Lockin, Tilden flouring mills.	10	7
Sec. 8, T. 30 N., R. 9 W	Bloomer mills, flour	12	
Eighteenmile Creek, Colfax	J. A. Anderson & Son, grist and saw mill.	14	
Hay River, Prairie farm	P. F. Milling Co., grist	9	
Jump River:			
Sec. 20, T. 34 N., R. 2 W		35	(a)
Westboro			
Lowes Creek, sec. 4, T. 26 N., R. 9 W	W. J. Davis	c 30	

a Undeveloped. b Unused. c Could be raised 8 feet.

Dams on smaller tributaries of Chippewa River—Continued.

Location.	Owner and use.	Head.	Installation.
		Feet.	*H. P.*
O'Neals Creek, west branch:			
Sec. 26, T. 31 N., R. 9 W	Wm. Durch, grist and saw mill.	8	30
Near mouth	F. G. & C. A. Stanley, sawmill.	22	50
Eagle Point	M. Rosmus, electric light	12	150
Otter Creek, Fau Claire	R. Clark, flour	18	95
Pine Creek:			
Lucas	T. Teegarden, grist and saw mill.	12	80
Sand Creek	A. F. Johnson, grist and saw mill.	6	96
Dalles	J. A. Anderson, grist and saw mill.	8	50
Plover River:			
Shantytown	S. Y. Bentley, sawmill	7	40
Jordan	A. Van Orden	14	100
Bevent	do	7	(a)
Rock Creek, sec. 22, T. 27 N., R. 11 W	D. W. Andrews, flour	35	75
Tiffany Creek, Boyceville	A. A. Hoyr & Bro., grist	9	30

a Undeveloped.

ST. CROIX RIVER SYSTEM.

TOPOGRAPHY AND DRAINAGE.

St. Croix River rises at an elevation of 1,010[a] feet, in St. Croix Lake, on the Lake Superior divide, only 20 miles from Lake Superior. The lower two-thirds of its length forms a part of the Minnesota boundary. In its total length of 168 miles it descends 344 feet, all but 20 feet of which is in the upper 116 miles, making the average for this upper portion nearly 3 feet per mile. This slope is fully six times the slope of Mississippi River above Minneapolis, and, according to United States engineers, has an important bearing on the relatively large run-off as compared with Mississippi Valley above. Another important feature of this region is its relatively small number of lakes, these forming only 3 per cent of the total drainage area as compared with 11 per cent in Mississippi Valley above Minneapolis.[a] Evaporation on lake surfaces is probably nearly equal to the precipitation for the corresponding period. The total drainage area comprises 7,576 square miles, the greater part of which is in Wisconsin. The Wisconsin portion has a width of 50 miles on its northern margin and extends southwesterly toward Mississippi River, a distance of about 150 miles.

The topography may be described under three heads—(1) the level area, (2) the rolling and swelling hill districts, and (3) the knoll and basin combination. The first includes the so-called "barrens" which border the streams and some elevated plateaus, together with smaller scattered areas. The third class may be described as a belt lying near the southeastern watershed and stretching from the vicinity of Lake Namekagon southwestward to the St. Croix. The second class includes most of the territory which remains.[b]

Marshes are quite as infrequent as the lakes and occur only on the river bottoms. Not half of the lakes are visibly connected with the rivers, but because of the open soil they are likely to have underground connection. There are usually lumbering dams on such lakes as have outlets, and these lakes, together with the numerous smaller depressions, play an important part in the preventing of freshets. The lakes of this region arrange themselves into two groups—one, lying mostly in the "barrens," adjacent and parallel to the upper St.

a Repts. Chief Eng. U. S. Army, 1881, 1883.
b *Geol. Wisconsin*, vol 3, 1880, p. 370.

Croix and extending southwest from its source to the point where the stream turns southward, and a second group in the extreme southeastern portion of this region, occurring in the depressions of the "Kettle moraine." As the water of this region flows almost exclusively over the crystalline rocks and sandstones, or the drift derived from them, it is in general soft, though usually amber colored. Springs are very common, many of the lakes being fed almost entirely by them. They are especially frequent in the Cambrian sandstone and tend to equalize the flow of all the streams.

The apportionment of drainage areas is shown in the following table:

Distances and drainage areas of St. Croix River.

River.[a]	Distance from source (map measure).	Drainage area above station.
	Miles.	*Sq. miles.*
St. Croix, source	.....	.....
Eau Claire:		
Above mouth	6.5	117
Mouth	6.5	224
Namekagon	38.0	1,451
Yellow	50.0	2,084
Clam:		
Above mouth	64.0	2,428
Mouth	64.0	2,844
Kettle:		
Above mouth	75.0	3,046
Mouth	75.0	4,139
Snake	79.0	5,097
Wood	84.0	5,281
Sunrise	100.0	5,857
St. Croix, St. Croix rapids	120.0	6,202
Apple	138.0	6,951
Willow	151.0	7,301
St. Croix, mouth	168.0	7,576

[a] Station is at mouth of river, unless otherwise stated.

PROFILE.

The following table gives, upon the authority of United States engineers, elevations above the sea and gradients per mile of St. Croix River at twenty points between its mouth and its source:

Profile of St. Croix River from its mouth to St. Croix Lake.

Station.	Distance.		Elevation above sea level.	Descent between points.	
	From mouth.	Between points.		Total.	Per mile.
	Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
ı of river	0.0	.....	[a] 667.0	.....	.....
er, mouth	5.0	5.0	668.0	1.0	0.2
ıuth	28.0	23.0	672.0	4.0	.2
.....	42.0	14.0	683.0	11.0	.8
head of navigation)	48.0	6.0	687.0	4.0	.7
›uth	60.0	12.0	753.0	6.6	5.5
nouth	65.0	5.0	758.5	5.5	1.1
r	75.0	10.0	773.0	14.5	1.4
R. 20 W	79.0	4.0	±782.0	9.0	2.2
›uth	86.0	7.0	±790.0	8.0	1.1
›ids, foot	89.0	3.0	±801.0	11.0	3.7
outh	90.0	1.0	±816.0	15.0	15.0
pids, head (proposed U. S. dam, sec. 2, W)	93.0	3.0	±850.0	34.0	11.3
uth	101.0	8.0	+868.0	18.0	2.2
R. 18 W	103.5	2.5	874.0	6.0	2.4
ıouth	115.0	11.5	888.0	14.0	1.2
·er, mouth	127.0	12.0	908.0	20.0	1.7
outh	139.0	12.0	1,001.0	93.0	7.7
, R. 13 W.:					
.....	144.0	5.0	1,001.5	.5	.1
.....	144.0	.0	1,005.3	3.8	.....
.....	160.0	16.0	1,010.0	4.7	.3

[a] Low-water elevation.

GEOLOGY.

entire watershed has been glaciated to such an extent that outcrops, except ı, are very infrequent. According to the reports of the Wisconsin Geological ntral and by far the greater portion of this area is underlain by the pre-Cam- ne rocks known as the "Keweenawan." This belt narrows toward the south, th on the east and west to the Cambrian sandstones. These pre-Cambrian ks intersect St. Croix River at St. Croix Falls, and because of their greater caused the falls and rapids—the most important on the entire river—which : 7 miles above the city of Taylors Falls, Minn.

RAINFALL AND RUN-OFF.

States Geological Survey has maintained a gaging station 3½ miles above St. 'is., since 1903. The gage heights are referred to four iron pins on the right w the gaging station, the elevations of which are referred to the datum of the ›f the St. Croix River survey. Their elevations are as follows.

	Feet.
.....	732.08
.....	734.54
.....	736.10
.....	737.57

ıber of measurements were obtained during 1903, and the gage was read daily day. Discharge measurements were made from a boat held in place by a wire d across the river between two trees. The initial point for soundings is a ver-

tical rod on the left bank. The channel is straight for about 800 feet above and 1,(below the station, while the banks are high and can not overflow. The section is smooth, and permanent, and the velocity is never sluggish, making this on the whol tion at which good results are obtainable. The drainage area at this point is 6,370 miles.

Discharge measurements of St. Croix River near St. Croix Falls, Wis., in 1903.

Date.	Hydrographer.	Gage height.	Dis
1903.		*Feet.*	*Sec*
May 22	E. Johnson, jr	4.00	
August 11	W. R. Hoag	2.70	
October 9	L R. Stockman	3.84	

Discharge data relating to St. Croix River near St. Croix Falls, Wis., obtained throu United States Geological Survey, have been supplemented by data supplied by Lo Wolf, civil engineers, of St. Paul, Minn. The results are embodied in the following ta

Daily discharge, in second-feet, of St. Croix River near St. Croix Falls, Wis., January 16 to December 31, 1904.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June	July.	Aug.	Sept.	Oct.	Nov.
1902.											
1	.....	1,820	2,425	2,910	3,930	5,150	6,690	2,270	1,725	2,330	5,190
2	.....	1,875	2,442	2,840	4,090	5,010	4,490	1,740	1,730	2,390	3,950
3	.....	1,930	2,460	300	3,910	4,480	4,830	1,790	1,680	2,395	3,290
4	.....	1,700	2,300	400	3,920	9,798	4,700	1,825	1,840	1,685	4,740
5	.....	1,760	2,370	2,750	3,935	11,871	7,350	1,870	1,700	2,150	3,910
6	.....	1,755	2,420	2,515	4,900	10,956	5,200	2,035	2,560	2,445	4,180
7	.....	1,750	2,270	2,280	3,980	10,610	12,106	2,260	2,550	2,390	4,030
8	.....	1,770	.....	2,280	4,880	.....	11,693	1,980	2,220	2,290	4,740
9	.....	1,765	.....	2,190	4,560	9,261	11,137	1,660	4,110	2,050	4,500
10	1,895	1,760	.....	2,110	4,500	10,468	12,947	1,990	3,500	930	3,290
11	1,910	1,750	.....	1,990	4,450	6,810	8,978	3,970	1,720	2,950	2,960
12	1,860	1,750	.....	1,870	5,850	7,600	7,980	1,680	1,500	1,950	3,195
13	1,850	1,815	.....	1,468	6,150	8,289	6,700	1,120	1,640	2,040	4,300
14	1,685	1,870	.....	2,065	5,250	4,780	6,060	1,015	1,550	2,000	4,530
15	1,765	1,990	.....	2,020	4,780	6,350	5,780	1,570	1,355	1,915	4,900
16	1,775	1,990	.....	2,170	4,875	4,220	4,860	1,590	1,355	800	4,600
17	1,795	1,990	.....	2,070	4,820	3,420	4,380	1,560	1,540	845	4,700
18	1,880	1,990	.....	5,190	4,940	3,580	3,800	1,500	1,480	3,600	4,580
19	1,860	1,990	4,650	1,510	5,065	6,350	5,210	1,510	1,120	1,940	5,160
20	1,920	1,990	4,995	1,005	5,300	3,780	2,850	1,500	510	1,925	3,690
21	1,875	1,990	4,650	500	5,870	960	3,405	1,480	2,800	2,040	4,665
22	1,930	1,990	4,600	5,540	7,080	3,300	3,530	1,480	2,070	1,980	4,160
23	1,860	2,027	4,035	440	9,600	3,400	3,600	1,575	2,540	2,040	4,250
24	1,950	2,065	3,470	510	7,250	6,000	3,185	1,495	2,365	850	4,060
25	1,985	2,110	3,110	1,050	6,420	3,560	2,560	1,405	1,065	1,100	3,720
26	1,975	2,180	3,117	2,760	5,585	4,145	7,250	3,850	1,135	2,300	3,555
27	1,950	2,260	3,125	3,025	5,760	4,380	850	1,860	1,120	2,310	3,680
28	1,930	2,480	3,125	3,290	5,090	4,200	750	1,740	3,050	2,660	3,060
29	1,920	.....	3,125	3,480	6,070	2,550	2,515	1,465	2,210	2,890	3,050
30	1,905	.....	3,037	3,750	4,930	4,690	2,515	5,995	2,310	1,875	2,050
31	1,890	.....	2,950	.....	5,290	.....	2,610	1,795	.....	2,840	.....

in second-feet, of St. Croix River near St. Croix Falls, Wis., January 10, 1902, to December 31. 1904—Continued.

b.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
50	1,940	6,770	8,920	7,680	251	4,570	.....	.....	.....	.....
35	1,920	9,800	9,555	10,420	3,030	4,800	.....	.....	.....	.....
60	1,920	10,750	.....	(9,490)	.....	5,050	.....	.....	.....	.....
30	1,960	12,220	.....	8,560	.....	6,170	.....	.....	.....	.....
00	1,965	.....	15,200	7,910	.....	6,710	.....	.....	.....	.....
15	1,885	10,350	15,611	7,340	8,640	1,600	.....	.....	.....	.....
30	1,990	8,850	15,176	(6,805)	.....	7,900	.....	.....	.....	.....
15	2,050	11,645	13,835	6,270	8,880	(7,600)	.....	.....	.....	.....
95	2,110	17,975	12,150	6,010	10,155	(7,280)	.....	.....	.....	.....
45	.....	16,438	.....	5,760	10,870	7,170	.....	.....	.....	.....
50	.....	18,272	9,245	5,160	11,630	4,830	.....	.....	.....	.....
80	.....	20,166	16,157	6,190	(10,437)	5,510	.....	.....	.....	.....
75	.....	.....	.....	7,320	9,245	5,340	.....	.....	.....	.....
30	.....	.....	.....	(6,910)	7,250	5,350	.....	.....	.....	.....
70	.....	15,382	.....	6,500	7,200	(4,792)	.....	.....	.....	.....
40	.....	14,080	.....	5,825	6,915	4,235	.....	.....	.....	.....
70	4,030	12,800	.....	5,130	6,790	4,150	.....	.....	.....	.....
70	4,530	.....	.....	5,755	6,035	3,460	.....	.....	.....	.....
50	6,480	12,540	.....	4,300	(5,592)	3,580	.....	.....	.....	.....
00	9,890	10,260	13,830	.....	5,150	4,360	.....	.....	.....	.....
45	11,440	.....	13,790	.....	4,540	4,740	.....	.....	.....	.....
30	11,460	.....	10,580	1,542	4,375	.....	.....	.....	.....	.....
10	11,480	.....	11,230	2,700	3,990	3,220	.....	.....	.....	.....
50	10,740	6,800	11,665	2,710	1,830	.....	.....	.....	.....	.....
45	9,660	9,740	12,100	2,640	5,590	.....	.....	.....	.....	.....
20	10,100	9,265	9,580	2,545	(4,670)	.....	.....	.....	.....	.....
80	9,530	8,790	12,020	(2,475)	3,750	.....	.....	.....	.....	.....
70	8,725	10,460	12,640	(2,420)	4,770	.....	.....	.....	.....	.....
...	8,590	10,080	11,420	2,360	4,730	.....	.....	.....	.....	.....
...	8,445	8,925	10,640	907	4,485	.....	.....	.....	.....	.....
...	8,160	.....	(9,160)	.....	4,570	.....	.....	.....	.....	.....
10	2,580	5,560	8,400	6,340	6,170	840	.....	3,950	8,780	1,690
90	2,570	6,130	7,500	5,520	5,850	1,080	4,530	(3,840)	8,040	1,760
60	2,520	(7,000)	7,540	6,050	(3,630)	1,480	4,610	3,720	7,590	2,210
40	2,390	8,080	7,480	7,950	1,410	3,460	(4,750)	3,360	6,780	(2,400)
80	2,290	9,873	7,380	(12,560)	(3,010)	2,250	4,900	11,310	3,280	2,620
70	2,390	12,390	8,290	17,180	4,610	1,990	4,870	1,240	(4,230)	2,740
40)	2,490	15,930	8,790	17,920	4,780	2,040	5,040	(2,800)	5,230	2,890
20	2,600	16,900	(10,320)	17,460	4,610	2,100	4,690	4,690	5,440	2,970
60	2,590	18,300	(11,850)	15,650	4,970	2,210	4,600	(3,400)	5,700	2,770
10	2,560	(16,600)	13,370	12,940	2,960	2,100	(4,030)	2,120	4,900	2,820
00	2,590	15,060	11,300	12,610	950	2,000	(3,460)	10,430	5,330	(2,820)
60	2,640	14,010	9,490	(12,070)	3,480	2,300	2,820	15,020	5,600	2,830
00	2,650	10,590	8,550	11,530	3,860	2,340	(2,380)	14,270	(5,540)	2,500
40)	2,660	7,910	8,980	11,320	3,750	(1,750)	1,940	13,800	5,470	2,420
80)	2,700	12,560	8,650	7,880	3,890	1,150	2,150	12,560	5,250	2,220
30	2,740	10,010	8,310	8,540	3,990	950	3,480	.....	4,970	2,380
30	2,690	(9,460)	7,280	7,628	(2,530)	1,430	3,190	10,060	4,770	2,330
60	2,700	(8,920)	7,820	8,140	1,080	3,370	(3,160)	10,760	4,570	2,320
10	2,750	8,380	6,860	8,710	1,140	1,920	3,140	10,310	4,480	2,300
50	(a)	7,850	5,250	9,280	3,760	2,240	2,890	12,710	(4,340)	2,380

[a] March 20 to 25, ice going out.

Daily discharge, in second-feet, of St. Croix River near St. Croix Falls, Wis., January 10, 1902, to December 31, 1904—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1904.												
21	2,440	(2,370)	.....	7,490	6,390	6,730	3,420	(3,760)	2,750	(15,700)	4,190	2,160
22	2,630	2,290	.....	7,530	(6,900)	5,630	3,170	5,290	2,380	18,700	4,030	2,440
23	2,620	2,330	.....	11,260	(7,500)	5,820	3,270	4,390	2,490	(18,010)	4,000	2,340
24	(2,570)	2,230	.....	(10,810)	8,000	4,960	(2,240)	2,520	2,700	17,330	4,120	2,300
25	2,520	2,280	.....	10,360	7,790	5,190	1,210	2,970	(3,240)	16,180	3,720	(2,420)
26	2,330	2,410	3,090	11,170	8,760	(3,380)	1,050	2,510	3,790	15,540	3,710	2,450
27	2,390	2,460	(3,370)	11,230	8,030	1,570	2,580	2,480	3,380	12,710	(3,300)	2,400
28	2,280	2,480	3,660	10,769	7,390	4,850	2,780	(2,230)	3,500	12,910	2,890	(2,440)
29	2,270	2,520	3,300	10,850	(6,700)	5,330	2,720	1,960	3,580	10,590	2,800	(2,420)
30	2,250	.....	3,770	9,490	6,060	5,320	2,810	2,260	(3,880)	(10,410)	(2,250)	(2,400)
31	.....	.....	4,510	.....	6,440	.....	.....	(3,000)	.....	10,230	.....	2,380

Estimated monthly discharge of St. Croix River at St. Croix Falls, Wis., for 1902, 1903, and 1904.

[Drainage area, 6,370 square miles.]

Date.	Discharge.			Run-off.		Rainfall.[a]
	Maximum.	Minimum.	Mean.	Per square mile.	Depth.	
1902.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Inches.*	*Inches.*
January	1,980	1,680	1,880	0.31	0.36	0.90
February	2,480	1,700	1,880	.31	.36	.54
March	5,000	2,380	3,300	.60	.69	.69
April	5,560	200	2,220	.37	.41	2.08
May	9,000	4,100	2,020	.33	.38	3.09
June	11,870	960	5,950	.99	1.14	3.59
July	12,106	760	5,500	.92	1.06	6.30
August	6,000	1,020	1,860	.31	.36	2.82
September	4,100	400	1,860	.31	.36	3.26
October	3,600	800	2,000	.33	.38	1.58
November	5,200	2,350	4,080	.68	.77	2.76
December	2,550	2,020	2,100	.35	.40	2.16
The year	12,106	200	2,912	.48	6.67	29.77
1903.						
January	2,040	1,740	1,920	.32	.37	.59
February	2,020	1,700	1,880	.31	.36	.88
March	11,480	1,960	5,500	.92	1.05	1.97
April	20,185	5,800	12,000	2.00	2.30	2.78
May	16,157	8,920	12,700	2.12	2.43	5.78
June	7,900	906	5,050	.84	.96	1.69
July	11,620	251	6,360	1.06	1.21	6.75
August	7,900	1,600	4,850	.81	.92	4.77
September	14,918	6,960	11,750	1.96	2.26	7.27
October	29,611	5,740	12,780	2.13	2.44	4.11
November	7,000	850	4,270	.71	.81	.66
December	3,440	2,340	2,740	.46	.52	.97
The year	29,611	[b] 251	6,816	1.14	15.63	38.22

[a] This is the average of the recorded precipitation at Barron, Duluth, Grantsburg, Hayward, Osceola, and St. Paul.

[b] Low water due to the [illegible]ation of a lumbering dam a few miles above.

nonthly discharge of St. Croix River at St. Croix Falls, Wis., for 1902, 1903, and 1904—Continued.

Date.	Discharge.			Run-off.		Rainfall.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth.	
1904.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Inches.*	*Inches.*
.....	2,840	2,200	2,600	.43	.48	.64
.....	2,480	2,000	2,238	.37	.42	1.18
.....	4,510	2,290	2,832	.47	.53	1.19
.....	18,300	5,560	10,748	1.79	2.01	1.65
.....	13,370	5,250	8,176	1.36	1.53	3.78
.....	17,920	4,850	8,868	1.48	1.66	5.58
.....	5,850	950	3,145	.52	.58	4.64
.....	3,460	840	2,334	.39	.44	3.84
.....	5,040	1,940	3,544	.59	.66	5.75
.....	18,700	1,240	10,560	1.76	1.98	5.47
.....	8,780	2,800	4,843	.80	.90	.05
.....	2,970	1,690	2,441	.40	.45	.99
ar.....	18,700	840	5,194	10.36	11.65	34.77

WATER POWERS.

FALL.

wer 48 miles of its course the St. Croix River has its bed in the Cambrian sand-
Lower Magnesian" limestone, principally the former, which it has succeeded in
wn nearly to base level, giving steamboat navigation from Taylors Falls, Minn.,
ppi River. Its descent in this distance of 48 miles is only 20 feet at low stages,
f which is found in the upper half between Stillwater and Taylors Falls. At Still-
miles above the mouth of the river, the sandstone bluffs rise steeply on either side
of 150 to 200 feet, and the river rapidly narrows. The bluffs continue, generally
on one side, between Taylors Falls and Stillwater. In the 24 miles below Still-
iver averages about half a mile in width, with a maximum of 7,000 feet at the
of the river known as St. Croix Lake, below Stillwater. For several miles here,
o reports of United States engineers, the river is almost without gradient.
ion of the St. Croix above Taylors Falls abounds in undeveloped powers. Except
adwaters of St. Croix, Totogatic, and Namekagon rivers and a small area served
n line of the Northern Pacific, running to Grantsburg, this region is without rail-
ies. The following detailed description of the main river above St. Croix rapids,
the Tenth Census, 1880, gives the most trustworthy information of the region

mouth of the Eau Claire to that of the Namekagon River there is a descent of 100 feet, or 4
, and many rapids occur, among which Copper Mine rapids may be mentioned. Above the
Namekagon the ordinary low-water power under a head of 10 feet would be 150 horsepower.
gon River increases this to 600 horsepower.
iles from the mouth of the Namekagon to the Yellow River the total fall is 20 feet, including
apids, State Line rapids, and Bishops rapids. Each of the first two is described as afford-
rtunities for developing water powers. At Big Island rapids the river runs close to the
left bank, but a dam would need to extend some distance across the flat on the right.
mouth of the Yellow River to the head of Kettle rapids, a distance of 21 miles, the average
et per mile, there being no rapids of special importance. It is very probable that available
sites can be found in this section.

ST. CROIX RAPIDS.

The St. Croix rapids offer fine opportunities for water power, and were used at one time, but r river flows unemployed. There is a total descent of 55 feet in the 6 miles which may be include the name of St. Croix rapids. Several local names are indefinitely applied at different points. foot are Taylors Falls, about three-quarters of a mile above are St. Croix Falls, then Turtle Fa Strictly speaking, there are no falls in the entire distance, only a more rapid decline in the bed at places.

The village of Taylors Falls is situated in Minnesota, at the foot of the rapids, about 50 mile the mouth of the river, at the head of navigation. St. Croix Falls, a village of Wisconsin, is si upon the slope overlooking the river from that side, nearly opposite Taylors Falls. Directly bel rapids the river enters the Dalles of the St. Croix, where for half a mile or more it passes between v cliffs of trap rock with sharp edges and bold angles. Just above the entrance into the Dalles th way is so contracted that when the river is high the water forms a fall of nearly 5 feet before it ca come the resistance, but there is no very rapid descent there in low water. It is to this portion river that the name of Taylors Falls is given.

Above the Dalles the rock continues in the bed, and to a certain extent in the banks of the riv the valley spreads considerably. On the Minnesota side the bank rises steep from the river for feet at the lower part of the rapids. Back from this for several hundred feet is a nearly level swampy in places; and bounding this are the bluffs, rising fully 100 feet higher. At the foot rapids the plain narrows and is lost in the Dalles. On the Wisconsin side, in the vicinity of St Falls, the slope is rather more uniform up to the general level of the country. At the entran the Dalles the river is scarcely more than 100 feet wide. At St. Croix Falls, three-quarters of above Taylors Falls, it is between 200 and 300 feet wide, the average width of the river in th of its course.

The portion of the rapids known as St. Croix Falls presents the most favorable site for impro of the power, and here a dam was once built and sawmills were run. The bed is solid rock, a banks rise abruptly from the river on both sides. On the Minnesota side a large, high mass of tr stands out in the channel and forms a natural abutment for a dam; on the Wisconsin side t bank rises to a considerable height above the water in a rib, and back of it is a depression whic to the slope upon which the village of St. Croix Falls is situated. The improvement, long since ruin, consisted of a dam built across the river at the point described, and a race blasted throu rock in the line of the depression on the Wisconsin side and then carried down the slope along t front, giving a head of 25 or 30 feet. The dam was a very extensive structure, raising the wat height of 25 feet when in good condition. It was 300 feet long, 24 feet wide at the top, and only wide at the base. . . . The same natural facilities exist for developing the water power as for . . . If the dam were built so as to give a head of about 40 feet, which is practicable, a race c carried down the plain on the Minnesota side for a long distance as readily as on the Wisconsin The pond would probably back the water 4 or 5 miles, and would not overflow much land. W ordinary low flow the power under a head of 30 feet is 7,811 theoretical horsepower, and under a 40 feet, 10,415 theoretical horsepower. With the yearly average flow it is 17,266 theoretical hors under a head of 30 feet, and 23,021 theoretical horsepower under 40 feet. There is about 5 feet o the river from the site of the dam to Taylors Falls. Here is an excellent site for the constructi dam, which would scarcely be more than 100 feet long, but the vertical cliffs come close to the riv below, leaving only room for a small steamboat landing, without space to erect extensive manufac

KETTLE RIVER RAPIDS.

The Kettle River rapids are, next to the St. Croix rapids, the most prominent on the river. start 2½ miles above the mouth of the Kettle River, which enters from the west, and end 1½ mile it. In this length of 4 miles the total fall is 49 feet, of which 34 feet is above the mouth of the River. Two islands from 1 mile to 2 miles long divide the river into two channels. The bed river is solid rock and it is practical to build several dams. Above the mouth of the Kettle head of 10 feet would afford 1,280 theoretical horsepower, with the ordinary low-water flow, an the entrance of the Kettle River 1,737 theoretical horsepower, under the same conditions of flow, ing to the estimates previously given.

Above the mouth of the Snake River, which enters 4½ miles below the Kettle River, there i of fall from the foot of the rapids. Between Snake River and St. Croix rapids are the following The Otter Slide, just below the mouth of the Snake, the ordinary low-water power of which, head of 10 feet, is 2,140 theoretical horsepower; the Horse Race, 1 mile below; the Baltimore r mile below the mouth of the Wood River, the ordinary low-water power of which, under a he feet, is 2,220 theoretical horsepower; the Upper Big Rock rapids, about 1 mile below them; Yellow Pine rapids, about 3 miles above the mouth of the Sunrise River. The amount of fall of these rapids can not be determined from the data at hand. The total fall from the mouth River to St. Croix rapids is 111 feet and the average slope is 2.64 feet per mile. This must furnis tunities to develop power with what will be a reasonable expense at some time in the future.

TRIBUTARIES OF ST. CROIX RIVER.

LENGTH AND DRAINAGE.

ength and drainage area of the principal tributaries of St. Croix River, including ıtering from the western (Minnesota) side, are shown in the following table:

Principal tributaries of St. Croix River.

River.	Length (map measure).	Drainage area.
	Miles.	*Sq. miles.*
re	25	107
gon	85	1,002
	50	310
	50	416
Minnesota)	70	1,093
Minnesota)	78	937
	30	168
	55	427
	35	246

YELLOW RIVER.

w River rises in a large lake called Mud Lake, at an elevation of 1,085 feet,[a] and sinuous course of 50 miles joins the St. Croix at a point only half this distance e source and at an elevation of 888 feet. This gives a descent of 197 feet, an aver- nearly 4 feet per mile. This high gradient results in rapids at frequent intervals ıout its entire course. The slope in the upper third of its length is about 120 feet. ›rings and creeks are numerous. The river is known to have a remarkably con- :age, the natural rise and fall during the year varying only from 1½ to 3½ feet. :t may be attributed to the springs and to the regulating effect of the large lakes, ly Yellow Lake, through which it flows. "Its valley is generally narrow, being)0 to 800 feet in width, although in some places it widens into tamarack marshes iderable extent. The first banks have a general elevation of 15 feet above low running back into high, broken ridges, covered with white Norway and jack pine. tone and few bowlders are found until reaching the rapids below Yellow Lake, .re almost continuous to the mouth of the stream."[a]

the mouth of the river the banks are high. A dam could be built in sec. 27, T. R. 16, which would develop a head of 25 feet or more and still not back the water ıe Yellow Lake dam. This power could be combined in the same plant with that :d by Loon Creek, which enters Yellow River near the proposed dam. Loon said to descend 50 to 75 feet in a distance of 1½ miles, and is therefore of considerable nce. A dam could also be located in Yellow River about a mile above Yellow ·hich would develop a head of 20 feet by overflowing some good meadow lands ı Yellow and Devils lakes.

[a] Rept. Chief Eng. U. S. Army, 1880.

The following profile of Yellow River suggests the possibility of developing other powers on this river because of its high gradient in ranges 14 and 13:

Profile of Yellow River from its mouth to Mud Lake dam.[a]

No.	Station.	Distance. From mouth.	Distance. Between points.	Elevation above sea level.	Descent between points. Total.	Descent between points. Per mile.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
1	Mouth of river			888.0		
2	Yellow Lake dam	7.0	7.0	928.0	40.0	5.7
3	SW. ¼ sec. 2, T. 39 N., R. 16 W	15.0	8.0	938.4	10.4	1.3
4	Rice Lake dam (SW. ¼ sec. 16, T. 39, N., R. 14 W)	34.0	19.0	969.4	31.0	1.6
5	SE. ¼ sec. 25, T. 39 N., R. 14 W	39.5	5.5	994.4	25.0	4.5
6	Sec. 31 (near north ¼ stake), T. 39 N., R. 13 W	40.5	1.0	1,004.8	10.4	10.4
7	SW. ¼ sec. 32, T. 39 N., R. 13 W	41.5	1.0	1,011.6	6.8	6.8
8	Harts (SE. ¼ sec. 5, T. 38 N., R. 13)	42.5	1.0	1,019.0	8.4	8.4
9	Sec. 36 (near north-south ¼ line), T. 39 N., R. 13 W	47.5	5.0	1,046.8	27.8	5.6
10	Spooner	49.0	1.5	1,058.0	11.2	7.5
11	Mud Lake dam (above)	52.0	3.0	1,085.0	27.0	9.0

[a] Authority: Nos. 1-9 and 11, U. S. engineers; 10, Chicago, St. Paul, Minneapolis and Omaha Rwy.

Important logging dams are described by United States engineers as follows:

Logging dams on Yellow River.

Name.	Location.	Head.	Capacity.	Remarks.
		Feet.	*Cubic feet.*	
Mud Lake dam	Sec. 27, T. 39 N., R. 12 W	7.5	475,000,000	
Hector dam	Sec. 10, T. 38 N., R. 13 W	7.5		Small capacity.
Rice Lake dam	Sec. 20, T. 39 N., R. 14 W	10.0	700,000,000	Head could be increased to 15 feet.
Yellow Lake dam	Sec. 7, T. 40 N., R. 16 W	18.0	1,400,000,000	Raises water in Yellow Lake 3 feet.

EAU CLAIRE RIVER.

Eau Claire River has its source in lakes of the same name at an elevation of 1,122 feet[a] above sea level. These lakes are surrounded by high banks, so that at small expense a dam could be constructed at their outlet and made to store surplus waters, thus adding greatly to all water power on the river. In its short length of 25 miles this river descends 118 feet, including several rapids, 46 feet of this descent being concentrated in the first 6 miles below Eau Claire Lakes. The total drainage area of the river is 107 square miles.

APPLE RIVER.

Apple River, like the Willow, occupies a comparatively well-settled valley. It drains an area of 427 square miles. The Wisconsin Central, the Chicago, St. Paul, Minneapolis and Omaha, and the Minneapolis, St. Paul and Sault Ste. Marie railways are distant 1 to 5 miles from the river, the last-named road crossing it near Amery. The river has its source in 20 or more lakes, the largest 6 miles long and one-half to three-fourths of a mile wide. These lakes tend to equalize and increase the summer flow. The long and severe winters cause the minimum flow during the months of January and February.

Formerly most of the dams on Apple River were used in connection with logging operations, but the timber is now practically all cut. Flouring mills have been maintained

[a] Rept. Chief Eng. U. S. Army, 1883.

ber of points, and at others the power is used for electric lighting. There are several ts at the present time which look to large improvements of some of these powers. ver in the first and last thirds of its course runs through the Cambrian sandstone, its middle third is through the "Lower Magnesian" limestone. In the lower third course the river flows over a rocky bed between rocky banks, giving ideal conditions ms. Most of the larger powers occur in this stretch, and some of these, developed ndeveloped, are described below:

The first power on the river is an undeveloped one located about 1½ miles from its ı. A dam at this point would give a head of 15 feet.

The second power, owned by the St. Croix Power Company, is located about 2 miles the mouth. Here a concrete dam of the arch type, 250 feet long and 47 feet high, ›ps a head of 82 feet.

Four miles from the mouth is a gristmill with a head of 11 feet, owned by E. E. Mason.

The next dam, located in sec. 35, T. 31 N., R. 19 W., develops a head of 18 feet.

Another dam, located in sec. 31, T. 31 N., R. 18 W., with a head of 22 feet, is owned, the name of the Apple River Power Company, by the Western Gas and Investment any of Chicago, which also owns No. 4, described above.

A dam 12 miles above the mouth of Apple River gives a head of 29 feet. The dis- e at this point is about 80 per cent of the total flow measured at the mouth. This is transmitted electrically to New Richmond, where it is used by mills and elevators.

: powers on Apple River of less importance are described in the following table:

Minor water powers on Apple River.

Location.	Owner and use.	Head.	Remarks.
mouth:		*Feet.*	
miles	H. L. Bixby, flour	11	Developed.
miles	M. C. Duggles & Jewett	8	Undeveloped.
miles (Star Prairie)	H. L. Bixby		Do.
miles	J. C. Schnyder, flour	12	Developed.
, T. 12. N, R. 13 W	Winger & Winger	2	Do.
alf mile above last site	J. Stucky, gristmill	12	Do.
	Northern Supply Co., elevators.	12	One-half total discharge developed.
Lake	Blake	12	Developed; can be made 18 feet.

ere are many other powers above Blakes Lake, with heads of from 6 to 20 feet, mostly gging dams in poor condition. When the region becomes more settled some of these s will be improved.

: following data on the discharge of Apple River for the year 1903 are furnished by Pearson, superintendent of the St. Croix Power Company, Somerset, Wis. The utations are based on the capacity of turbines located at a point 2 miles from the h of Apple River. The average daily discharge for each month is as follows:

Estimated daily discharge of Apple River near Somerset, Wis., for 1903.

Month.	Discharge.	Month.	Discharge.	Month.	Discharge.
	Sec.-feet.		*Sec.-feet.*		*Sec.-feet.*
ary	258	May	860	September	690
uary	239	June	468	October	660
h	600	July	492	November	362
l	555	August	380	December	324

WILLOW RIVER.

Willow River, one of the smaller tributaries of the St. Croix, has a high gradient, due to the fact that its bed lies in the "Lower Magnesian" limestone for its entire length. It drains an area of only 246 square miles and has a length of about 35 miles. In the lower two-thirds of this distance, between Hudson and Jewett Mills, it descends 213 feet, giving many opportunities for water power. Many of these powers are improved, as the river traverses a fairly rich and well-settled country and is paralleled for a considerable distance either by the Wisconsin Central or the Chicago, St. Paul, Minneapolis and Omaha Railway. The powers are here briefly described in order, beginning at the mouth:

1. A timber dam at Hudson 100 feet long gives a head of 16 feet, and with improved machinery would develop 117 horsepower at ordinary low water. A part of this power is used occasionally for electric light when the power described as No. 3 is short of water.

2. Two miles from the mouth of Willow River a dam formerly developed a 9-foot head and was used for driving a flouring mill. At present this dam is washed out.

3. The 130-foot dam of the Willow River Electric Light and Power plant, 3½ miles from the mouth of the river, gives a head of 22 feet, sufficient to develop 200 theoretical horsepower at ordinary low-water flow. The power is used to generate electricity for lighting the city of Hudson, Wis., and for pumping its water supply.

4. A timber dam 100 feet long, 5½ miles from the mouth of Willow River, gives a head of 24 feet, sufficient to develop about 125 horsepower. This power is used for a flouring mill. About 1,200 feet below this dam there is a fall of about 47 feet, and at this point a new dam could be erected, which could be made to include the 24-foot dam above, giving a total head of 71 feet. Such a dam would need to be about 26 feet high and about 70 or 80 feet long. By carrying the water a short distance below in a penstock, a total head of 105 feet could be secured, sufficient to develop about 600 horsepower at ordinary flow of water. This site, being where the river bed changes from the "Lower Magnesian" limestone to the Cambrian sandstone, affords ideal conditions for a dam. The town of Burkhardt, on the Chicago, St. Paul, Minneapolis and Omaha Railway, is located about a mile distant.

5. Seven miles from the mouth of Willow River a 100-foot timber dam gives a head of 16 feet. This power is used to run dynamos.

6. Rapids occur 8½ miles from the mouth of Willow River. A dam 125 feet long at this point, located at comparatively small expense in a narrow limestone gorge, could be made to develop a head of 22 feet.

7. At a point about 11 miles from the mouth of Willow River the Boardman flouring mills were formerly located. The 80-foot timber dam at this point was washed out some time ago, but the mill still stands. If the dam were replaced, a head of 16 feet or more could be easily developed. All the above powers on Willow River are owned by C. Burkhardt, who has the right of flowage wherever needed along this stretch of 11 miles, giving an aggregate descent of nearly 200 feet.

8. The next power on Willow River is located at New Richmond. A timber dam 40 feet long, owned by the New Richmond roller mills, develops a head of 18 feet.

9. The last dam on this stream is located at Jewett, 5 miles east of New Richmond. Power afforded by a 10-foot head is owned by P. Newell & Hennesey and used in a feed mill and sawmill. Above this point Willow River is too small for water-power use.

CLAM RIVER.

Clam River drains an area of 416 square miles. It is formed by two branches—North Fork and South Fork—which unite near the center of the drainage area just above Clam Lake. The river descends about 350 feet in a total length of 50 miles, and, as much of this high gradient is concentrated at rapids, several good opportunities are offered for development. The river flows through a comparatively thinly settled region, which as yet has no railroads. Several railroads, however, cross the margins of the drainage. The

following statements regarding its principal water powers are based on information given the writer by Edward L. Peet, editor of the Journal, Grantsburg, Burnett County.

A large, unimproved water power exists in T. 40 N., near the line between Rs. 17 and 18 W. At this point the banks of Clam River are 80 to 150 feet high, and the land which would be flooded is low and of little value. Above the proposed dam the valley bottom will average half a mile wide, with a few expansions to 1½ miles. The bed of the river is clay and bowlders, mixed with sand. Plenty of timber for the construction of a dam grows in the swamps close at hand. Bowlders are also abundant at the dam site. The levels taken on a recent survey show that this power could be improved in the following ways: A dam 6 rods long at the range line would give a head of 20 feet. A dam 10 rods long built farther downstream would produce a head of 35 feet. By adding a 6-foot embankment for a distance of 20 rods this head could be increased to 28 feet; or a dam 60 rods long could be built across the valley with an average height of 40 feet and a maximum height of 85 feet. If the water were conducted by canal a distance of about a mile to the lowlands adjacent to St. Croix River, turbines could be installed with a head of 100 feet. This dam site is distant only 3 miles from other large, undeveloped powers on St. Croix and Yellow rivers, with which it could be easily and cheaply connected by electric transmission.

About half a mile below Clam Lake there is now a logging dam with a head of about 20 feet which raises the water in the lake 3 or 4 feet. This dam impounds the water from a drainage area of 283 square miles. United States engineers reported that a dam would need to be 560 feet long at this point to produce a head of 25 feet. Such a dam would have a capacity of 4,670,786,000 cubic feet,[a] and if properly regulated could be made to greatly increase the amount and value of the powers below. The engineers found that the bed of the river consisted of sand from 3 to 20 feet, at which depths soundings indicated hard materials, supposed to be clay and gravel.

Another large water power is found at Clam Falls, in sec. 13, T. 37 N., R. 16 W., where the river falls over a wide ledge of the "Keweenawan" rocks. A dam at this point impounds the drainage from an area of 45 square miles and develops a head of 34 feet. Between Clam Falls and Clam Lake the slope is small and the river valley half a mile to 1½ miles wide. The river profile is shown in the following table, compiled from surveys made by United States engineers:

Profile of Clam River from its mouth to Clam Falls.

Station.	Distance.		Elevation above sea level.	Descent between points.	
	From mouth.	Between points.		Total.	Per mile.
	Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
Mouth of river			868		
St. Croix, road crossing	6.0	6.0	881	13	2.2
Clam Lake, mouth	19.0	13.0	947	66	5.1
Sec. 35, T. 38 N., R. 16 W., south line	29.0	10.0	967	20	2.0
Clam Falls	32.5	3.5			

NAMEKAGON AND TOTOGATIC RIVERS.

Namekagon River rises in a large lake of the same name near the divide in the watersheds of Chippewa and Bad rivers. Its drainage area is second in extent of all the St. Croix tributaries. Namekagon Lake is formed by six or more connected lakes, occupying parts of 14 sections and surrounded by extensive cedar and tamarack marshes. In the upper 60 miles of its course the river is generally narrow and swift, stretches of rapids over

[a] Rept. Chief Eng. U. S. Army 1880, p. 1619.

pre-Cambrian crystalline rock being frequent.[a] There are also several vertical falls of 2 to 4 feet, which, together with the rapids, furnish good opportunities for water powers. The banks are high on either side, stretching away into high, broken ridges and sand barrens covered with timber. In the remaining 25 miles of its length the river is from 100 to 200 feet wide. In this reach it descends 130 feet, including several sharp pitches and rapids, the principal of which are Little and Big Bull rapids and Dupee flats. The average slope of the river is 5.3 feet per mile.

A good location for a dam is found 4 miles above the mouth of the river, where the high gravel banks approach within 600 feet. A head of 20 feet or more could be obtained here without overflowing much land, impounding the drainage from 1,000 square miles. With the ordinary low-water flow estimated at one-third of a second-foot per square mile, this would produce 740 theoretical horsepower. Because of the storage effect of the present dams above this point, the river at this site might be made to produce nearly 1,000 horsepower. Another good location for a dam is found at Veazie, on the Chicago, St. Paul, Minneapolis and Omaha Railway. By overflowing 6,000 acres, mostly railroad and Government land, a head of 30 feet could be obtained, according to United States engineers. A dam of 15 feet head would cause little overflow. Such a dam would have the run-off from about 800 square miles and at ordinary low water would produce 275 theoretical horsepower. Small dams are located at Stinnett and at the outlet of Lake Namekagon. A dam owned by the Hayward Electric Light and Power Company, located near Hayward, develops 200 horsepower and is used for light and power purposes in that city.

Additional information regarding undeveloped powers is given in the following profile:

Profile of Namekagon River from its mouth to Cable, Wis.[a]

No.	Station.	Distance.		Elevation above sea level.	Descent between points.	
		From mouth.	Between points.		Total.	Per mile.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
1	Mouth of river	.....	.....	±908.0	.....	.....
2	Sec. 33, T. 43 N., R. 14 W., east side	4.0	4.0	917.8	9.8	2.4
3	Totogatic River, mouth	5.0	1.0	918.0	.2	.2
4	McKinzie Creek, mouth, sec. 28, T. 42 N., R. 13 W.	13.0	8.0	944.0	26.0	3.2
5	Stuntz Brook, mouth, sec. 27, T. 42 N., R. 13 W.	15.0	2.0	952.0	8.0	4.0
6	N. E. ¼ sec. 34, T. 41 N., R. 13 W	16.0	1.0	958.0	6.0	6.0
7	NW. ¼ sec. 6, T. 40 N., R. 12 W	19.5	3.5	990.0	32.0	9.0
8	Sec. 18, T. 40 N., R. 12 W., near center	21.5	2.0	1,004.5	14.5	7.2
9	Sec. 39, T. 40 N., R. 12 W., near center	24.0	2.5	1,024.2	19.7	7.9
10	SW. ¼ sec. 27, T. 40 N., R. 12 W	25.5	1.5	1,025.2	1.0	.7
11	Veazie, sec. 36, T. 40 N., R. 12 W	28.5	3.0	1,039.0	13.8	4.6
12	River Jordan, mouth, sec. 21, T. 40 N., R. 11 W	35.5	7.0	1,058.0	19.0	2.7
13	Spring Brook, mouth, sec. 15, T. 40 N., R. 11 W	37.0	1.5	1,068.0	10.0	6.6
14	Chippenacia Creek, mouth, sec. 33, T. 40 N., R. 10 W	43.0	6.0	1,115.0	47.0	7.8
15	Stinnett	45.0	12.0	1,136.0	21.0	10.5
16	Little Puckanance	59.0	14.0	1,218.0	82.0	5.9
17	Cable, Bayfield County	70.0	11.0	1,303.0	85.0	7.7

[a] Authority: Nos. 1-14, and 16, U. S. engineers; 15 and 17, Chicago, St. Paul, Minneapolis and Omaha Railway.

In its length of 55 miles, Totogatic River, the principal tributary of the Namekagon, descends 350 feet. It enters the main stream only 5 miles above its mouth. The region is high and precipitous, with frequent ledges of pre-Cambrian crystalline rock and bowlders. As a result, the stream forms for miles a series of rapids with many vertical falls of 10 feet or more. Many logging dams already exist, the most important being located

[a] Simar, V. B., Asst. U. S. Engineer: Rept. Chief Eng. U. S. Army, 1880, p. 1616.

s follows: Sec. 13, T. 42 N., R. 10 W.; sec. 6, T. 42 N., R. 10 W.; and sec. 12, T. 43 N., . 10 W. A good site for a dam is near the outlet of Gilmore Lake, in sec. 9, T. 42 N., R. 2 W.; and another in sec. 12, T. 42 N., R. 12 W. The following profile of Totogatic iver is compiled from surveys made by United States engineers:

Profile of Totogatic River from its mouth to NE. ¼ sec. 15, T. 42 N., R. 9 W.

Station.	Distance.		Elevation above sea level.	Descent between points.	
	From mouth.	Between points.		Total.	Per mile.
	Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*
outh of river			918.0		
c. 13, T. 42 N., R. 13 W., dam	11.5	11.5	975.5	57.5	5.0
E. ¼ sec. 10, T. 42 N., R. 12 W	20.0	8.5	1,008.8	23.3	2.7
E. ¼ sec. 3, T. 42 N., R. 10 W	37.0	17.0	1,168.4	159.6	9.4
E. ¼ sec. 13, T. 42 N., R. 10 W	40.0	3.0	1,241.6	73.2	24.4
E. ¼ sec. 15, T. 42 N., R. 9 W	50.0	10.0	1,251.6	10.0	1.0

MINOR STREAMS.

Osceola Creek.—Emptying into St. Croix River a few miles south of Willow River is a nall stream known as Osceola Creek. In the city of Osceola, near its mouth, is a water ower with a head of 90 feet, owned by the Osceola Mill and Elevator Company. This am furnishes the power to run a mill with a capacity of 175 barrels per day. One-fourth f a mile above is another dam with a head of 26 feet.

Kinnikinnic River.—A small river emptying into St. Croix River only 5 miles above its outh bears this name. Its gradient is so high that there are a number of good sites for vater powers. The descent in 10 miles is 190 feet. The following is a tabulated statement f its water power:

Water powers on Kinnikinnic River. [a]

No.	Location.	Owner and use.	Head.	Estimated horsepower.	Remarks.
			Feet		
1	2 miles from mouth	N. Kohl, flouring mill	10	70	Timber dam.
2	5 miles from mouth				Good dam location.
3	7 miles from mouth		20		
	River Falls:				
4	3 miles below		14		
5	1 mile below	City waterworks	15	60	Timber dam, 9 by 120.
6	River Falls	do	39	140	Timber dam.
7	do	Geo. Fortune, mill and elevator	8	40	Timber dam, 4 by 210.
8	do	Prairie mill and elevator	14	60	Timber dam, 12 by 180.
9	7 miles above River Falls.	Clapp's mill	10		Dam out.
10	South Branch, sec. 1, T. 27 N., R. 19 W.	W. H. Putnam, feed and flour	50	30	Timber dam, 25 by 114.
11	1 mile above No. 10	Glass Bros., manufacturers	14		
12	Balsom Lake	J. W. Park, lumber and flour		180	

[a] Figures are low-water estimates. Nos. 1 and 5-12 developed; 2-4, undeveloped.

LAKE SUPERIOR DRAINAGE SYSTEM.

TOPOGRAPHY.

The watershed which limits the area of Lake Superior drainage in Wisconsin varies in elevation (above the level of Lake Superior) from 600 feet near the Minnesota line to over 1,000 feet near the Michigan line. Its average distance from Lake Superior is only 30 miles. For this reason the rivers are comparatively small; but owing to the fact that their high gradient, 600 to 1,000 feet, is largely concentrated at a few points, they offer many opportunities for water-power development. From a point near the center of the watershed a wide and nearly flat table-land, of which Bayfield Peninsula and the Apostle Islands form the northern prolongation, separates the drainage into eastern and western sections of nearly equal area. In both of these sections three distinct belts of topography are usually distinguished. The southernmost belt consists of a plateau in large part covered with swamps and lakes and is so flat that in many cases the water from the same swamps and lakes may flow either north to Lake Superior or south to the Mississippi.

From this flat watershed the descent northward is gradual until a range of mountains from 600 to 900 feet above the level of Lake Superior is reached. The northern slope of these mountains is much steeper than their southern slope, forming a marked though not continuous escarpment.

In the western section these mountains, known as Douglas Copper Range, reach a height of 400 to 600 feet above the lake and have a width of 1 to 4 miles. They extend in an east-northeast direction, gradually merging into the Bayfield moraine. From the crest of the mountains there is a sudden descent of 300 to 400 feet, caused by a faulting of the rocks. The Lake Superior rivers break through the ridges at this point, and here the greatest opportunities for water-power development are to be found.

In the eastern section the mountains, called the Penokee Iron Range, extend from a point on the Michigan boundary, 12 miles from Lake Superior, in a southwesterly direction for about 35 miles, gradually merging into the plateau. As in the western section, many falls and rapids occur in breaking through the hard "Huronian" rocks of which the range is composed. Smaller falls continue for a distance of 5 to 6 miles after crossing the Penokee Range, or until the Copper Range has been crossed.

To the north of the highlands and extending with a gradual slope northward to the shores of Lake Superior lies a plain with a width of 5 to 15 miles. Its northern portion reaches an elevation of 100 to 200 feet above Lake Superior or 700 to 800 feet above the sea. The entire belt is underlain by till and deep layers of red clays sometimes mixed with sand. The rivers, both large and small, have cut deep and narrow banks in the clay soil. As a result the surface is carved in every direction by narrow water courses whose steep sides have a height of 25 to 100 feet, making railroad and highway construction expensive. Very few swamps are found in this lowland area. Because of the gradual slope of the shallow rivers opportunities for water-power development in this belt are rare. In many cases, however, there are important falls at the immediate mouths of the rivers and over the red sandstone-

WATER POWERS.

CHARACTER.

Owing to the fact that the rivers of the Lake Superior system in Wisconsin have a total fall of 400 to 1,000 feet in the narrow belt of 30 miles separating the plateau region in which they rise from Lake Superior, their currents are characteristically rapid. As a result the rainfall is quickly discharged, the streams alternating between small creeks and torrential rivers. While the storage of surplus waters is important everywhere in the State for the economical development of water power, it is here doubly so. The fact that the most important falls and rapids are in the upper half of the drainage area increases the difficulty of storing a large proportion of the rainfall. With a storage of less than 5 to 15 per cent of the rainfall most of the rivers would furnish at low water an insignificant flow.

Rainfall data regarding this drainage area are scanty, but sufficient to show that the rainll increases from the lake to the highlands. This fact is strikingly shown by the precipition map published by the United States Weather Bureau and shown in fig. 1 (p. 16). It here seen that the rainfall increases southward at the average rate of about 5 inches every 5 miles, the maximum not being reached until after the highlands are passed. This fact as an important bearing on the value of the water powers, because, as already stated, it cessitates the location of reservoirs to a large extent in this region of greatest rainfall. he most important water powers occur near the Copper ranges and the Penokee Iron ange, where future mining operations may render them of much economic importance.

ST. LOUIS RIVER.

Although the water powers of St. Louis River lie outside the State, they are located so ear the Wisconsin boundary that development contemplates their extensive use in Supe-

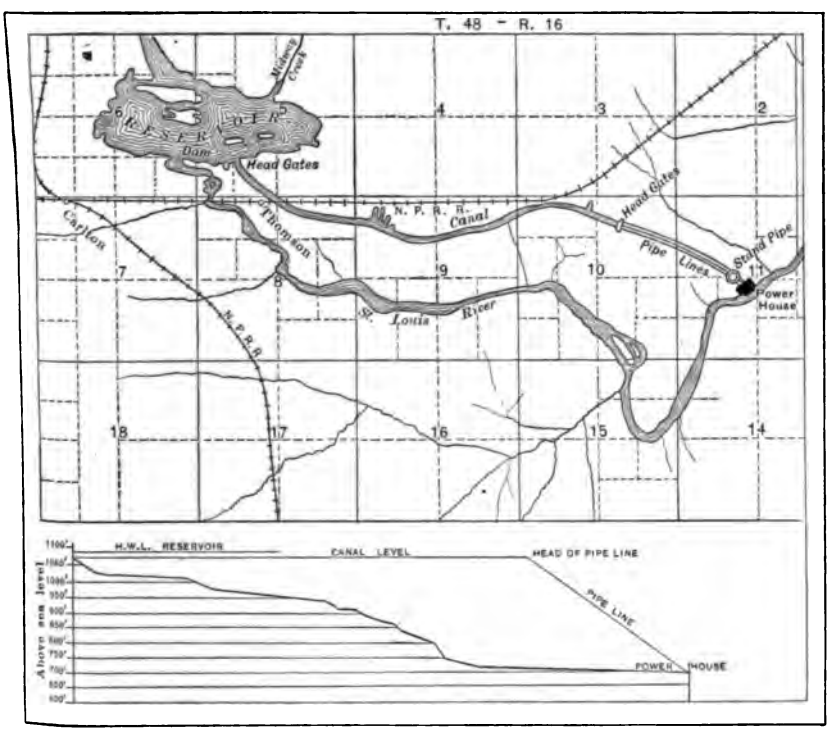


FIG. 5.—Plan of canal of Great Northern Power Company, St. Louis River.

rior and other Wisconsin cities. An important feature of St. Louis River is the concentration of its descent in the lower reaches, where its volume is greatest. This provides opportunities for water power which if distributed among its smaller tributaries would be in large part wasted. The upper portions of St. Louis River are sluggish, flowing through many lakes and swamps, but as the waters near the lake their speed is increased until at a point about 22 miles from Lake Superior, just above Fond du Lac, there is a series of falls and rapids extending 6 miles upstream from a point 2 miles from the Wisconsin boundary. In this distance of 6 miles the river descends 456 feet in a series of wild leaps over the upturned ledges of slate rock, forming a water power which has few superiors in the West. This power and the riparian rights are owned by the Great Northern Power Company. Mr.

F. A. Cokefair, chief engineer of the company, furnishes the following statement under date of January 23, 1904:

One steel gravity dam 36 feet high and 620 feet long has already been constructed near the village of Thompson. This dam conserves the water in a reservior of about 1 square mile of area, from which the water is led through a canal 2½ miles long, 62 feet wide, and 15 feet deep. (Fig. 5.) From the terminus of the canal the water is taken by iron pipes for a distance of about a mile and delivered under a head of 365 feet at the power house midway between Thompson and Fond du Lac. The capacity of this canal is sufficient to develop 100,000 horsepower. Final plans and designs are now completed, and work on the first station for the ultimate development of 100,000 horsepower will begin in the early spring. Bids have been asked from leading manufacturers for the first three wheels of 12,500 horsepower capacity each, the largest units ever yet built and similar to those in use at Niagara Falls. Transmission lines will carry the power to the neighboring cities of Duluth and Superior, and even farther to the Mesabi and other iron ranges, where it will augment or displace steam power.

NEMADJI AND BLACK RIVERS.[a]

Unlike other rivers of the Lake Superior watershed, Nemadji River flows northeast instead of north and does not rise in an elevated region. As a result it is devoid of important rapids or falls suitable for water power.

Black River, the most important tributary of the Nemadji, rises in an elevated country, its source being in a lake on the Minnesota boundary. It flows north and empties into Nemadji River about 10 miles from Lake Superior at an elevation of only 20 feet above the lake. In the upper two-thirds of its length Black River flows through many tamarack and cedar swamps, which give to its waters a distinct color and taste. Up to about 4 miles from the Douglas Copper Range it occupies a wide valley with small descent. As this range is approached the valley narrows and its gradient increases. In the SE. ¼ sec. 28, T. 47 N., R. 14 W. the hard layers of the "Keweenawan" rocks cross the river, producing a vertical fall of 31 feet A total head of 160 feet[b] could easily be obtained here for a dam site. As Black River has a drainage area of 80 square miles above these falls, an assumed run-off of 0.4 second-foot per square mile gives 560 theoretical horsepower. A company was formed some time ago to improve this power, and a franchise was secured from the city of Superior for lighting by electricity, but no construction has yet been done. The water at the head of the upper rapids is 387 feet above Lake Superior; at their foot, 50 yards beyond, the elevation is 227 feet. From this point the river passes for nearly a mile through a gorge 100 to 170 feet deep, below which the walls of the gorge are less elevated above the stream, but the current is very rapid until it joins Nemadji River 4 miles below. From the foot of Black River Falls to the junction with the Nemadji the total descent is 200 feet, an average of 50 feet to the mile.

BOIS BRULE RIVER.

Though over 33 miles long, Bois Brule River has a drainage area of only 200 square miles, practically all of which is in the highland district. It rises in a swamp, near St. Croix Lake, at an elevation of 420 feet above the level of Lake Superior. In sec. 15, T. 46 N., R. 10 W., at the Dalles, Bois Brule River is only 25 feet wide, with banks of clay and bowlders averaging 8 feet in height. Near this point there are swift rap ds, with a total descent of about 15 feet in 200 yards. Similar rapids about 3 miles farther north, near the township line, continue as far as the mouth of Nebagemain River, the most important tributary of the Bois Brule, in sec. 27, T. 47 N., R. 10 W. For the next 10 or 12 miles the current is very sluggish until the head of the lower rapids is reached, in sec. 26, T. 48 N., R. 10 W. From this point to within 1½ miles of Lake Superior rapids and small falls (the largest being 4 or 5 feet in height) occur almost continuously. These descend an aggregate of 200 feet over "Keweenawan" eruptives and sandstones. By constructing dams at the outlets of Lakes Nebagemain and Minnesung the surplus water could be held

[a] The authority for most of the statements concerning the Lake Superior rivers is Prof. R. D. Irving: Geology of Wisconsin, vol. 3, 1880.
[b] Sweet, E. T., Geol. Wisconsin, vol. 3, 1880, p. 319.

ack and used at times of low water, thus adding greatly to the value of the water powers n the river. At present there are no dams. Mr. Howard Thomas, city engineer of Supe- or, Wis., states that the normal discharge of this river is 100 second-feet, and that at sev- al points heads of 40 feet could be obtained by dams between bluffs or with dams and umes along the banks. Such a head would give 450 theoretical horsepower. Because of s comparatively small watershed and the fact that the river is fed very largely by springs is not subject to freshets.

MONTREAL AND GOGOSHUNGUN RIVERS.

For nearly its entire length Montreal River forms a part of the Michigan-Wisconsin bound- y. It rises in a tangle of lakes and tamarack swamps near the boundary line at an ele- ation of about 1,600 feet above sea level, or 1,000 feet above Lake Superior. Its length 50 miles, the highest gradient being concentrated in the last quarter of this distance. his exception to the general rule of the Lake Superior drainage area is due to the fact at here the Penokee Iron Range and its associated highlands of the "Keweenawan" series proach Lake Superior within a distance of only 3 miles, leaving no lowland region.

About 1,300 feet from its mouth, on the north line of sec. 7, T. 47 N., R. 1 E., is a verti- l fall of 35 feet over sandstone. It is stated by an officer of the Duluth, South Shore nd Atlantic Railway that a head of 55 feet could be developed here by constructing a ume 100 feet long. Because of the lakes and swamps at the headwaters of this river it is cely that at least 5 per cent of the annual rainfall could be stored in reservoirs. This ould give, from its 280 square miles of drainage area, an ordinary flow of 140 second-feet, quivalent, with a head of 55 feet, to 868 theoretical horsepower. In the last five-eighths a mile of its course Montreal River descends 90 feet. The railway official mentioned ove also states that another power site is located in the NW. ¼ SW. ¼ sec. 21, T. 47 N., . 1 E., at falls of 60 feet over the crystalline rocks. As the banks are high, a 20-foot am, with a flume 250 feet long, would develop a head of 80 feet. Both of the above pow- s are within 4 miles of the Duluth, South Shore and Atlantic Railway. At Ironwood, bout 2 miles above these falls, the river has an elevation of 880 feet. In the 5 miles above ronwood the river descends only 30 feet, and for the remainder of its upper reaches its urrent is slow. At all the rapids on this river the conditions are favorable for the build- ng of dams.

The Gogoshungun, a branch of the Montreal, is nearly as large as the upper Montreal, eing about 30 miles long. Its total descent is 500 feet. Until the river reaches the Peno- kee Range its current is sluggish, being bordered by swamps. In its passage through the mountains, in sec. 27, T. 46 N., R. 2 E., a number of rapids and falls occur.

BAD RIVER.

MAIN RIVER.

The sources of Bad River lie in large swamps 8 miles south of the Penokee Iron Range, t an elevation of 900 feet above the level of Lake Superior. In this distance of 8 miles its escent is 110 feet, but its course is sinuous, as may be inferred from the fact that the Wis- onsin Central Railway is forced to cross it eight times. About 1½ miles above Mellen are pids called Copper Falls, which have a total descent of about 60 feet. (Pl. V, *B*.) The ver at this point has a drainage area of about 144 square miles. According to a survey, per cent of the annual rainfall could be easily stored in dams near the headwaters, which ould provide an ordinary flow of 68 second-feet, equivalent to 460 theoretical horse- wer.

Near the Penokee Range Bad River enters a gorge of pinkish granite, narrowing in places a width of 10 feet and descending 20 feet in 30 rods, with a total descent of 50 feet in ee-fourths of a mile. The river then widens and continues with reduced grade until okee Gap is reached, when it again contracts. Coming into contact with the "Huro- n" rocks, it flows along their strike. In the next 4 miles occur many rapids and several

falls, including one of 35 feet. In the next 1,000 feet, in which the river descends 40 feet, Tylers Fork, the most important tributary, is reached. Directly at the junction Tylers Fork has a fall of 45 feet over the wall of a gorge 65 feet deep. This is in sec. 17, T. 45 N., R. 2 W. A competent engineer, reporting on this water power, states that dams could develop here a head of about 120 feet. The tributary drainage area is given at 234 square miles. On the assumption that the rainfall is only 32 inches and that reservoirs can be made to store 15 per cent of the rainfall, it was estimated that the river would furnish a continuous flow of 206 second-feet, equivalent to about 3,000 theoretical horsepower. It was proposed to conduct this power electrically to Ashland.

In the next 1,000 feet below Tylers Fork the river flows through a rocky gorge 100 feet deep, beyond which the rocks disappear and the stream flows between high banks of red clay, the ground rising rapidly on both sides. The total descent in sec. 17 is probably 135 feet. In the next 6 miles of its sinuous course, to the mouth of Maringouin River, the river descends about 30 feet to the mile. Both rivers at their confluence are broad and deep, with slow-moving, muddy currents and wide bottom lands—conditions which continue to the mouth of Bad River.

Farther north, 2¼ miles from this junction, Bad River receives the waters of Potato River. At this point its elevation is 80 feet above the level of Lake Superior. In sec. 25, T. 47 N., R. 3 W., occur some small falls, of 1 or 2 feet, over red sandstone and shale, which continue for perhaps 2 miles. Below these falls Bad River continues sluggish, deep, and tortuous, with bold and high clay banks, until White River is reached. For the remainder of its course the river finds its way to Lake Superior through swamps.

TRIBUTARIES.

The principal tributaries of Bad River, named in order from its mouth, are as follows: White River entering from the west; Potato River from the east; Maringouin or Mosquito River from the west, and Tylers Fork from the east.

White River.—This river, the largest tributary of Bad River, has a total length of about 45 miles, and drains an area of 400 square miles. It rises in Long Lake, at about 700 feet above the level of Lake Superior. Most of its descent is concentrated in its upper waters, where its discharge is least. It pursues a general northeasterly course, with many windings through high and steep clay banks, like those described on Bad River. Its only considerable falls are in sec. 6, T. 46 N., R. 4 W., where the river was originally obstructed by the edges of southward-dipping rocks. A dam with a 20-foot head has been maintained here for several years, and until October, 1903, furnished the power to run a paper mill. At that time the mill burned, and it has not been rebuilt. It had turbines rated at 710 horsepower. The owner, George Davidson, reports that he has a charter for a dam with 30-foot head, to be located about 1,300 feet upstream. The main dam as planned would be 125 feet long, with an embankment 10 to 12 feet high and 900 feet long. Mr. Davidson also states that about 500 feet below the present dam there is a location for a dam with a 9-foot head. At three dam sites the bed of the river is in sandstone which extends 10 feet above the water surface. The rock is overlain with red clay.

Maringouin River.—Maringouin River, sometimes also called Maringo (Mosquito) River, has a total length of about 40 miles and drains an area of 231 square miles. Four miles from its source it crosses the Penokee Range. Here, in the NW. ¼ sec. 23, T. 44 N., R. 5 W., the river descends, in a series of three falls, a total distance of 65 feet within a few rods. The two upper falls, of 15 and 25 feet, respectively, are only 50 feet apart. Nothing but the limited amount of water prevents this from being a valuable water power. For the remainder of its course the river is devoid of falls or rapids, flowing between high clay banks.

Within 6 miles of its junction with Bad River, the Maringouin receives several rapid tributaries, the most important of which is Brunsweiler Creek. This creek rises in the same swamp with Maringouin River, but, unlike it, has important falls north of the "Huroman" hills. Until Bladder Lake is passed in sec. 11, T. 44 N., R. 4 W., the cur-

luggish. The outlet of this lake is only 6 feet wide, with rock walls on either side. which would greatly raise the water in the lake could be constructed here at slight . At the outlet of the lake there is a long series of chutes and rapids for a dis- over 6 miles. In this stretch the creek flows through a narrow valley with steep, ills. The last important descent occurs near the north line of sec. 22, T. 45 N., where the stream leaves the Copper Range, the slope being 30 feet in a distance et.

Fork.—This tributary is the only one which joins Bad River before the lowlands hed. Tylers Fork, nevertheless, has a length of 30 miles and a total descent of . Until it reaches the Penokee Range its current is sluggish. In the NE. ¼ sec. 5 N., R. 1 W., the river falls 20 feet over the hard "Huronian" rock. Less than a ther on, in sec. 28, occurs a series of low falls over black slate, the descent being 20 distance of 500 feet. On the north line of sec. 20 the river surface is 760 feet e level of Lake Superior. In the next 10 miles of its course it descends 260 feet, out any considerable rapids. On the west line of sec. 15, T. 45 N., R. 2 W., the n of the water is 485 feet. The current now becomes swifter and about a quarter e below the east line of sec. 16 is a series of rapids which continues to its junction d River, ending in the 45-foot fall already described (p. —). As these falls and re within a mile of the Wisconsin Central Railway, they seem destined to become economic importance.

River.—In its course of only 30 miles, Potato River has a total descent of over . The river is small until it is joined in sec. 15, T. 46 N., R. 1 W., by Little Potato From this confluence a course nearly due west for 12 miles takes it to Bad River. east line of sec. 17, T. 46 N., R. 1 W., at 428 feet above the level of Lake Superior, s of rapids followed by a series of cataracts. These rapids begin on the east line W. ¼ sec. 17, T. 46 N., R. 1 W., and are in the trap rock. In the next quarter mile descents of 10, 4, and 40 feet occur, with swift water between. A still larger fall t or more is located near the west line of sec. 17, and as the banks are high and us, a suitable dam would develop a head of nearly or quite 100 feet. On both the west line of sec. 17, about 2,000 feet north of the southwest corner, is a series falls having a total descent of 80 feet in a distance of 500 feet, with two leaps of and 32 feet, respectively. The total fall in secs. 17 and 18 is 170 feet. These ing over solid rock of conglomerate and sandstone, furnish ideal conditions for Below sec. 18 the river course is tortuous and slow.

MINOR RIVERS.

icon, Middle, Poplar, and Iron rivers are small streams in Douglas County They swift streams with many small falls, but are subject to great variations of flow, significant at low water. A corporation known as the Iron River Water, Light er Company has recently constructed a dam 135 feet long, with a head of 32 feet, River, in sec. 22, T. 47 N., R. 10 W., the intention being to install turbines of 1,000 wer, which will be transmitted to near-by towns.

RAILROADS.

e falls which occur near the Penokee Range on Bad River and Tylers Fork are Wisconsin Central Railway. Montreal and White rivers are crossed by the South Shore and Atlantic, the Chicago and Northwestern, and the Wisconsin railways. The western half of the Lake Superior watershed has good transporta- ilities. Branches of the Great Northern Railway cross the valley of Black River ow the valley of Nemadji River. Besides these the drainage is crossed by the n Pacific, the Chicago, St. Paul, Minneapolis and Omaha, and the Minneapolis, , and Sault Ste. Marie railways, and by minor logging roads.

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATER

IN THE

LLEYS OF UTAH LAKE AND JORDAN RIVER, UTAH

BY

G. B. RICHARDSON

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UNDERGROUND WATER IN THE VALLEYS OF UTAH LAKE AND JORDAN RIVER, UTAH.

By G. B. Richardson.

INTRODUCTION.

The valleys of Utah Lake and Jordan River are situated in north-central Utah, in the extreme eastern part of the Great Basin. The lofty Wasatch Range (Pl. I), the westernmost of the Rocky Mountain system, limits the valleys on the east, and relatively low basin ranges—the Oquirrh, Lake, and East Tintic mountains—determine them on the west. The valleys trend north and south, and are almost separated by the low east-west Traverse Range, the slopes of which constitute a dam for Utah Lake, which drains through Jordan River to Great Salt Lake.

The area under consideration is the most populous and flourishing part of the State. Salt Lake City and Provo, the first and third cities in the State, and many other thriving settlements are there located. At Bingham Junction and Murray a number of smelters treat the ores from near-by mines, but agriculture is the main industry. Water for irrigation is supplied by mountain streams, and intensive farming is successfully pursued. The practice of irrigation was begun by the Mormon pioneers in 1847, and has been discussed in several publications; little attention, however, has been given to the underground water resources, and, so far as the writer is aware, they have not before been described. The present paper outlines conditions of occurrence of the subterranean waters and describes their development in the valleys of Utah Lake and Jordan River.

TOPOGRAPHY AND DRAINAGE.

The drainage area of Utah Lake and Jordan River is approximately 3,300 square miles, of which 2,600 are tributary to Utah Lake and 700 to the Jordan north of the Traverse Mountains (Pl. II). About 2,000 square miles of the watershed are in the Wasatch Mountains, while the valleys themselves cover a little less than 1,000 square miles. Utah Lake Valley is about 38 miles long, averages 15 miles in width, and occupies about 560 square miles, including Utah Lake. Jordan Valley is approximately 28 miles long, 15 miles wide, and comprises 420 square miles. These valleys in late geologic time were occupied by Lake Bonneville, the Pleistocene predecessor of Great Salt Lake, and to that fact is due their characteristic topography. Almost flat unconsolidated lake sediments underlie the broad valleys, the borders of which are marked by a unique series of terraces that characterize the shore lines of the old lake. Descriptive details of these features will be given in the sections devoted to geology and to the occurrence of underground water.

The range in elevation is considerable. The present level of Great Salt Lake is approximately 4,210 feet above the sea, and that of Utah Lake is about 4,480 feet. From these lowest elevations the two valleys rise to their outer borders, which may conveniently be taken as the highest level occupied by Lake Bonneville, at approximately the 5,200-foot contour, above which the Wasatch Range towers up to 12,000 feet. The mountains on the west are narrow north-south ranges that rise abruptly from broad valleys. The

Oquirrh Mountains, west of Jordan River, are 30 miles long, 5 to 10 miles wide, and their summits rise to elevations of about 10,000 feet. The Lake Mountains, west of Utah Lake, are about 15 miles long, 5 miles wide, and 3,000 feet above the lake. They are connected by low hills with the Oquirrh Mountains on the north and with the East Tintic Mountains on the south. The East Tintic Mountains border Utah Lake Valley on the southwest, rising above it about 3,000 feet. A spur from these mountains extends northeastward, constituting the southern border of Utah Lake Valley, and almost unites with the Wasatch Range. The steep western face of the Wasatch Mountains rises about 7,000 feet abruptly above the broad valley and constitutes the dominant topographic feature of the region. To the east the range slopes away gradually in a series of broad ridges and narrow valleys to the mountainous plateau region. The western scarp is deeply dissected by canyons, through which the entire Wasatch drainage flows to Great Salt Lake, the chief streams being Bear, Weber, and Jordan rivers.

Utah Lake is a body of shallow water about 21 miles long and 7 miles wide (Pl. III, *A*), covering a maximum area of 93,000 acres. Its depth over much of its extent is only 8 feet or less, and the maximum depth in the main body of the lake is about 13 feet. In its northwestern part, however, recent soundings have revealed the presence of several deep holes, due to springs (p. 49). The shore line of the lake is subject to considerable variation, owing to the changing relations of evaporation, precipitation, and inflow, and the margins are characteristically swampy. Two large, shallow bays extend eastward and southward from the main body of the lake, one south of Provo and the other north of Goshen. West of the lake the Pelican Hills approach close to the shore, and the region is barren, but on the north, east, and south the land rises gently toward the base of the mountains and is dotted with flourishing settlements which are supported by irrigation.

The principal streams tributary to Utah Lake, beginning at the north and proceeding southward, are: Dry, American Fork, Battle, and Grove creeks, Provo River, Hobble Creek, Spanish Fork, and Peteeneet, Santaquin, and Currant creeks. Of these, Provo River is the largest, being approximately 70 miles long and having a drainage area of 640 square miles. It rises in the Uinta Mountains near the sources of Weber, Bear, and Du Chesne rivers, flows westward and southward through Kamas and Provo valleys, and passes through the Wasatch Mountains in a deep canyon. On entering Utah Lake Valley Provo River flows almost due south for 5 miles, skirting the great Provo delta, and thence westward, entering Utah Lake about 3 miles west of Provo.

Spanish Fork has a watershed about equal to that of Provo River, but not so great a discharge. It rises near Soldier Summit, and, after receiving two main tributaries, North and Thistle creeks, flows in a canyon through the main ridge of the Wasatch Mountains and enters Utah Lake Valley at the head of the large embayment that extends between Payson and Springville.

Salt Creek rises in the southern Wasatch Mountains, on the eastern slope of Mount Nebo, and, after crossing the border of the plateau region, emerges into the broad valley at the southwestern base of the Wasatch Mountains where, in summer, it ceases to flow at the surface. The drainage way continues, in a narrow canyon, through Long Ridge which partially connects the East Tintic and the Wasatch mountains, and enters the southern end of Utah Lake in Goshen Valley, where the stream, which is fed largely by seepage, is known as Currant Creek.

The other tributaries of Utah Lake are relatively small. The chief ones rise in the Wasatch Mountains and occupy canyons in their mountain courses, where they maintain perennial flows. At the mouths of the canyons canals divert the water and distribute it over the valley, so that in the irrigation season practically all of the available supply is thus used and the beds of the streams in Utah Lake Valley are commonly dry; but in the late spring and early summer, during the period of melting snow, large volumes are discharged directly into the lake.

Jordan River heads at the northern end of Utah Lake and flows northward in a meandering course of about 40 miles to Great Salt Lake. For the first 5 miles the river flows slug-

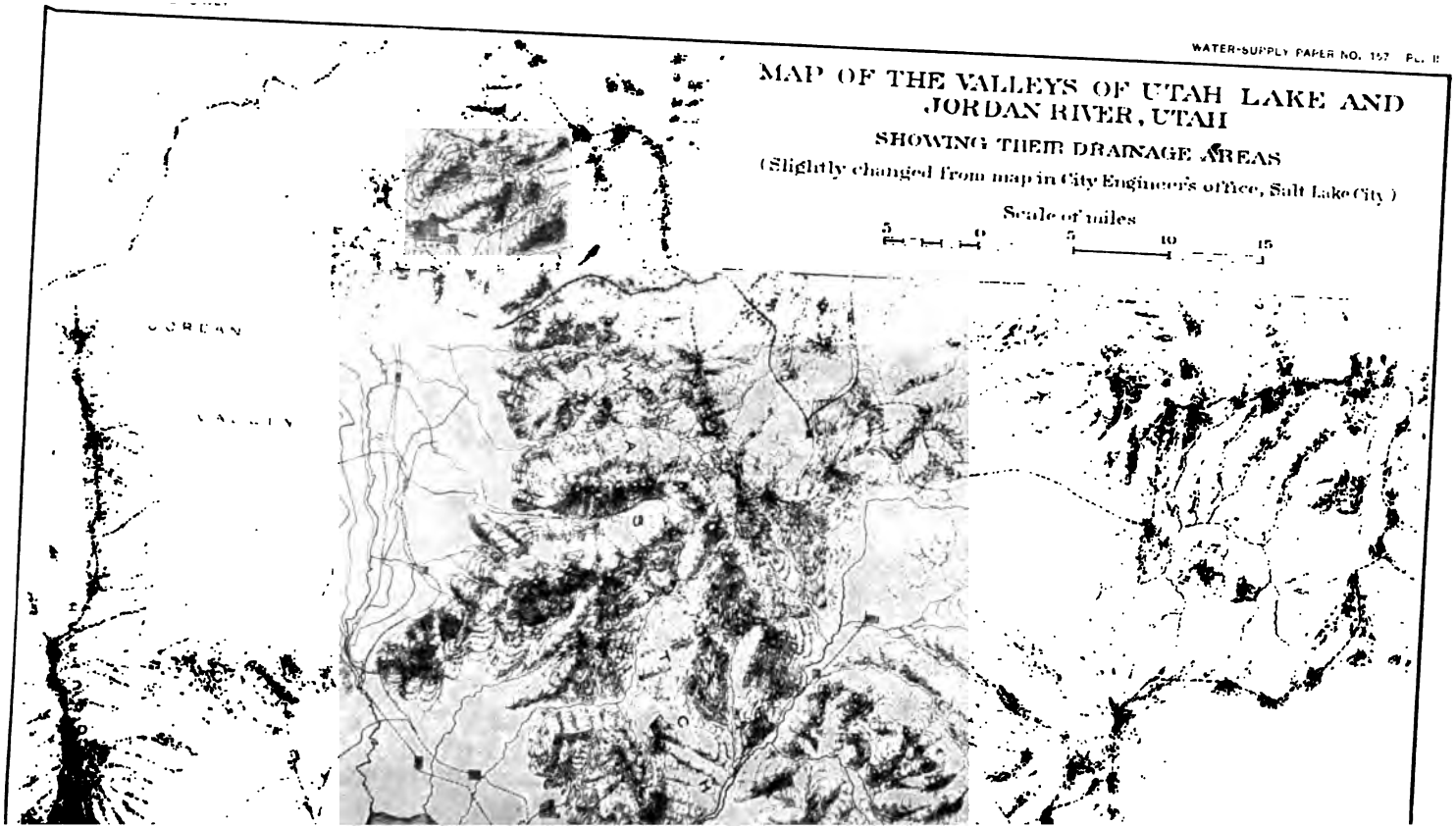
MAP OF THE VALLEYS OF UTAH LAKE AND JORDAN RIVER, UTAH

SHOWING THEIR DRAINAGE AREAS

(Slightly changed from map in City Engineer's office, Salt Lake City.)

Scale of miles

5 0 5 10 15



UTAH LAKE
UTAH
CEDAR

hly in a broad valley, and in that distance falls only about 10 feet. In the "narrows," wever, the river occupies a constricted channel and descends rapidly; in the first mile ow the intake of the canals its fall amounts to about 70 feet. Below the "narrows" the lley spreads out and at its greatest width is about 18 miles wide. The country rises gradu- y toward the adjacent highlands to the base of the terraces that mark the shore lines of ke Bonneville, whence the ascent is by successive steps. Between Salt Lake City and eat Salt Lake the topography is almost flat, and a number of small lakes of shifting out- e occupy local depressions. As the shore of Great Salt Lake is approached there is a nt slope of the surface which becomes increasingly marshy. This area west of Salt Lake y in general is barren and desolate and the surface in many places is white with alkali. the uplands, away from the lake, alkali is scarce, but the western part of the valley, ause of the lack of water, suffers in comparison with the cultivated eastern part, which supplied by streams from the Wasatch Mountains.

North of the Traverse Mountains the principal tributaries of Jordan River are City, Red tte, Emigration, Parleys, Mill, Big Cottonwood, Little Cottonwood, Dry Cottonwood, and llow creeks, all of which issue from the Wasatch. In their mountain courses these creeks nerally occupy narrow canyons from which they emerge on the lowlands and flow in broad en valleys to the Jordan. Within the mountains they are all perennial streams, but at mouths of the canyons their flow is largely diverted by irrigation ditches, so that, in the rest part of the year, their lower courses are generally dry. They rise in the main crest the Wasatch and have small watersheds, Big Cottonwood Creek, draining about 48 square les, being the largest. This stream rises at the base of Clayton Peak, is fed by a number small lakes, and discharges a considerable quantity of water through a narrow canyon l. IV, *B*).

The vegetation is scanty. The valleys in their natural state are occupied by sagebrush, easewood, and kindred desert plants, but wherever water is available there is a marked ntrast, and the irrigated areas of these valleys rival in productiveness any in the country. gar beets are grown in quantity; alfalfa, potatoes, corn, etc., are common crops; and on e bench lands a variety of fruits are successfully cultivated. The mountains on the estern border are generally barren; sagebrush and occasional cacti are the chief growths the slopes, while scrub oak and stunted spruce and pine here and there grow in tches; the summits are usually bare. The Wasatch Mountains are more favored, but ey do not support a heavy growth of trees. At the heads of the valleys scattering ne, juniper, mountain mahogany, and quaking aspen locally occur, and cottonwood, birch, d maple are often found near the stream beds. The slopes are commonly covered with derbrush in varying degrees of thickness, sagebrush and scrub oak being prominent.

GEOLOGY.

LITERATURE.

This area has been studied by prominent geologists and has inspired some classic works American geology. King, Emmons, and Hague of the Fortieth Parallel Survey[a] inter- ted the main features of the region, and Gilbert made it famous by his investigation of ke Bonneville.[b] But although this interesting region lies contiguous to one of the main nscontinental routes and has been visited by many geologists, yet comparatively little ailed work has been done in it. Walcott[c] has studied the Big Cottonwood Cambrian tion, G. O. Smith and G. W. Tower[d] have examined the Tintic district, J. E. Spurr[e] has

King, Clarence, Systematic geology: Rept. Geol. Explor. 40th Par., vol. 1, 1872; Hague, Arnold, and mons, S. F., Descriptive geology: Ibid., vol. 2, 1877.

Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890.

Walcott, C. D., Bull. U. S. Geol. Survey No. 30, 1886, p. 38.

Tower, G. W., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: Nine- th Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 601.

Spurr, J. E., Economic geology of the Mercur mining district, Utah. Sixteenth Ann. Rept. U. S. l. Survey, pt. 2, 1896, p. 343.

reported on the Mercur mines, and, more recently, work has been carried on in the Park City and Bingham mining districts by J. M. Boutwell.[a] The following sketch is mainly compiled from these reports.

DESCRIPTIVE GEOLOGY OF THE HIGHLANDS.

The Wasatch Mountains are composed of a complex mass of sedimentary, igneous, and metamorphic rocks that have been much folded and faulted. In age the rocks range from pre-Cambrian to Tertiary and constitute a thickness of about 50,000 feet. The following table shows in epitome the main Paleozoic divisions according to the Fortieth Parallel Survey:

Paleozoic section in the Wasatch Mountains.

System.	Formation.	Average thickness.
		Feet.
Carboniferous	Upper Carboniferous limestone (including Permian)	2,500 to 3,000
	Weber quartzites with a few thin beds of limestone	5,000 to 7,000
	Wasatch limestone	7,000
Devonian	Ogden quartzite	1,000 to 1,250
Silurian	Ute limestone	1,000 to 1,250
Cambrian	Big Cottonwood quartzite series (clay slates at top)	12,000
		30,000

The present mountains are the eastern part of a greater mass of rocks, the Wasatch Range having been raised by faulting several thousand feet higher than the western part of this mass, which now lies buried beneath the valley deposits. This great fault is the dominant structural feature of the region. The range rises abruptly 7,000 feet above the wide lowland at its base, where the streams, which in their mountain courses occupy deep-cut narrow gorges, flow in wide valleys. The fault cuts across the range regardless of the structure of the rocks, and the truncated mountain bases abut against the plain in marked alignment.

Beginning at the north and proceeding southward the following features may be noted: The spur that juts out from the Wasatch Mountains north of Salt Lake City marks the southern boundary of a series of pre-Cambrian rocks that constitute the crest and western flanks of the mountains to the northwest, almost as far as Ogden. These rocks for the most part consist of gneisses and mica-schists, considered to be of sedimentary origin, with which are associated quartzites, slates, and some igneous rocks. In general the strike is N. 20° W., and the prevailing dip is westerly at angles ranging from 15° to 20°. A great thickness of coarse Tertiary conglomerate lies high up on the northeastern flanks of the range, but at the southeastern end of the crystalline area Paleozoic sediments abut against the older series and dip southeastward.

An outlying mass of nearly horizontal coarse Tertiary conglomerate, composed chiefly of pebbles of limestone and quartzite, caps the spur of the mountains north of Salt Lake City and conceals the older sediments except along the western base of the spur, where the Wasatch limestone outcrops. A small isolated body of volcanic rock outcrops in the midst of the Tertiary area and is bisected by City Creek. The headwaters and upper course of City Creek lie in Paleozoic rocks, chiefly in the Weber quartzite and Wasatch limestone, which dip southeastward at angles varying from 30° to 65°. Across the divide a large area of flat-lying Tertiary rocks cap the disturbed Paleozoic series.

[a] Boutwell, J. M. Progress reports Park City mining district: Bull. U. S. Geol. Survey No. 213, 1903, pp. 31-40; No. 225, 1904, pp. 141-150; No. 260, 1905, pp. 150-153. Economic geology Bingham mining district: Prof. Paper U. S. Geol. Survey No. 38, 1905 (with a section on areal geology by Arthur Keith and an introduction on general geology by S. F. Emmons).

Between City and Big Cottonwood creeks the summit and western face of the mountains e occupied by an immense syncline striking nearly east and west. Its western end is rminated by the Wasatch fault, which cuts directly across the fold and exposes the structure so that it can be plainly seen from Jordan Valley. The axis of the syncline coincides pproximately with the course of Emigration Creek. In detail, however, the structure is omplicated by a number of relatively minor disturbances.

East of Salt Lake City upper Carboniferous and Permian strata, consisting chiefly of limeone, outcrop between City and Red Butte creeks, and dip southward, forming the northern mb of the syncline. Red Butte Canyon lies in Permo-Carboniferous rocks, but near the outh of the canyon "Red Beds" outcrop and continue along its southern divide. The Red Beds" consist chiefly of red shales and sandstones, aggregating over 1,000 feet in ickness and are overlain by thin-bedded, argillaceous limestones and shales of Jurassic ge. These rocks occupy the center of the syncline, and outcrop in the valley of Emigration reek.

South of Emigration Creek the summit and western face of the Wasatch Mountains are ccupied by the southern limb of the syncline as far as Big Cottonwood Creek, and the ccession of rocks mentioned above is repeated in reverse order. The dips generally are orthward, but there are minor folds and faults.

Parleys Creek rises in the Cretaceous sandstone and conglomerate that, east of the main Vasatch ridge, lie unconformably upon the older rocks. After traversing this area it crosses narrow belt of Red Beds and, for 5 miles above the mouth of its canyon, flows over calcareis and argillaceous Permo-Carboniferous rocks. Carboniferous strata occupy the divide etween Parleys and Mill creeks, the latter of which flows for the greater part of its length the Weber quartzites.

Between Mill and Big Cottonwood creeks the lower Paleozoic rocks outcrop. Big Cottonood Creek exposes for 6 miles above the mouth of its canyon a great thickness of Cambrian rata, consisting of siliceous slates and quartzites; in the upper part of its course this creek rosses the Weber quartzite and Wasatch limestone, and heads in the crystalline rocks of layton Peak. Little is known of the occurrence of Silurian and Devonian sediments in is area. Their presence was recorded by the early surveys, but the little detailed work at has been done shows that in a few localities at least these systems do not appear to be epresented by sediments.

Little Cottonwood Creek for about 8 miles from the mouth of its canyon flows through a rystalline area, and heads in Paleozoic strata and igneous rocks at the foot of Clayton 'eak. The western base of the mountains extending north and south of Little Cottonwood 'reek is occupied by a belt of schistose rocks about 10 miles long and averaging perhaps 1 ile in width. These rocks are of pre-Cambrian age and are over a thousand feet thick. 'hey consist largely of quartzite, but include also slates and mica-schists, having an apparnt steep western dip. Up Little Cottonwood Creek, beyond the pre-Cambrian area, lies large body of granitic rocks, which forms high peaks north and south of the creek, and hrough which the stream flows for the greater part of its course. The Paleozoic sediments rch around this granitic area, dipping away from it to the north, east, and south, forming dome the western part of which has been cut off by the Wasatch fault.

The age of the "Little Cottonwood granite" has been the subject of some discussion. It learly cuts the pre-Cambrian rocks at the mouth of the canyon, but its relation to the 'ambrian was not definitely determined by the early surveys, though the granite was hought to be of pre-Cambrian age. Recently, however, it has been shown[a] that the 'granite" is an intrusive mass that cuts the Cambrian quartzite, though the age of the ntrusion is not yet known.

Partial topographic connection between the Wasatch and Oquirrh ranges is maintained by the Traverse Mountains near the head of Jordan Valley, but this connection furnishes little information concerning the relations of the two main mountain masses, because the

[a] Emmons, S. F., *Am. Jour. Sci.*, 4th ser., vol. 16, August, 1903, p. 139.

Traverse Mountains are largely composed of younger lavas, which conceal the rocks upon which they lie.

In the "narrows" where Jordan River flows through the Traverse Mountains, practically horizontal Pleistocene gravels, which form the great embankment at the point of the mountain, are unconformably underlain near the river level by fine-textured sediments that dip southeastward at an angle of 40°. The lower part of these sediments consists of light calcareous clay and the upper part of fine sand and gravel. No fossils were found, but the marked unconformity and the character of the material suggest that the age of the lower deposits is Tertiary.

East of Utah Lake the great Wasatch fault is impressively shown by the remarkable alignment of the base of the mountains extending from Spanish Fork Canyon to the Traverse Mountains in an approximately straight line, and by the abrupt rise of the mountains above the broad valley. Second and third lines of faulting, lying parallel to the main fault and east of it, are suggested by the topography, which rises steplike, with two intervening treads between the ascents, to the top of the main ridge, and by the unusual thickness of limestone exposed, which apparently requires repetition by faulting for the explanation of its occurrence.

In this part of the range a disturbed belt of rocks with prevailing steep westerly dips occurs along the western base of the mountains, beyond which the strata dip eastward at low angles and the summits of the main ridge are capped by limestone lying almost flat. The streams that cross the mountains, therefore, flow transversely to the strike of the rocks, in marked contrast to the creeks farther north, whose courses lie approximately parallel to the strike.

Excellent sections can be measured along the canyons, but very little detailed work has yet been done. The rocks in general are quartzite and limestone of Carboniferous age, but locally Cambrian sediments also occur. In Rock Creek Canyon, east of Provo, in the lower end of the gorge, the rocks are much disturbed and are complexly folded. Here a considerable thickness of white quartzite outcrops, overlain by a great mass of limestone. In a thin bed near the base of the limestone G. H. Girty obtained a few Cambrian fossils, and about 600 feet above, in massive gray limestone, the beds being apparently conformable, he found Lower Carboniferous fossils.

South of Hobble Creek easterly dips prevail from the base of the mountains as far as Spanish Fork, beyond which the range has been very little studied. It trends southwestward and terminates at Mount Nebo, the main mass of which is composed of steeply west-dipping limestone and subordinate quartzite of upper Carboniferous age. The highland farther south consists of a series of plateaus, which are underlain by low-lying Mesozoic and Tertiary rocks.

The highlands that border the valleys of Jordan River and Utah Lake on the west are for the most part composed of the same rocks that occur in the Wasatch Mountains, but the structural relations are completely hidden by the deep filling of the intervening valleys.

The Oquirrh Range is composed mainly of Carboniferous limestones and quartzites, which, in the southern part of the mountains, are folded into two parallel anticlines with an intervening syncline. The axes of folding are obliquely transverse to the topography, the range extending in a north-south direction while the structural trend is northwestward. The structure of the northern part of the mountains is little known, but the range is probably terminated by a fault. Rocks of Cambrian age are exposed locally by a fault in the vicinity of Mercur, and igneous rocks, both extrusive and intrusive, also occur. The intrusive rocks include both acidic and basic porphyries, which are conspicuous in the vicinity of the mining camps of Bingham and Mercur; the extrusive rocks, largely andesitic, occur principally along the eastern base of the range and in the Traverse Mountains.

The Lake Mountains, or Pelican Hills, west of Utah Lake, are composed of Carboniferous limestones and quartzites which constitute a low synclinal fold, and are separated from the Traverse Mountains by a narrow strip of Pleistocene deposits. A line of hills

composed chiefly of west-dipping limestone, separate the Lake Mountains from the East Tintic Range—the succeeding highland mass to the south. The northern end of these hills is capped by horizontal basalt with which light pumiceous tuff is associated.

The East Tintic Range, a complex mass of sedimentary and igneous rocks, forms the southwestern border of Utah Lake basin. As in Rock Canyon, the sediments consist of Cambrian quartzite and Carboniferous limestone in juxtaposition, indicating the absence of the Ordovician, Silurian, and Devonian. The main structure of the sedimentary rocks is synclinal, but these constitute a relatively small part of the outcrops, igneous rocks, rhyolite, andesite, monzonite, and basalt occupying most of the region. These are of both extrusive and intrusive origin, and are of Tertiary age. The low spur of the Tintic Mountains known as Long Ridge, which lies south of Goshen and connects with the Wasatch—save for a narrow Pleistocene strip south of Santaquin—consists of andesite in its southern part, while southeast-dipping Carboniferous limestones outcrop in the gorge of Currant Creek.

LATE GEOLOGIC HISTORY.

The above résumé implies for this region a complex geologic history which need not here be discussed. A statement of late geologic events will, however, add to a clearer understanding of the valley deposits in which the underground water is stored.

TERTIARY HISTORY.

After many thousands of feet of sediments had accumulated in Paleozoic and Mesozoic time, during which the general region was occupied by oceanic waters, profound continental uplift occured in early Tertiary time. Since then the ocean has not invaded the interior of the continent and during Tertrary time much of the Cordilleran region is believed to have been occupied by a number of lakes in which a considerable thickness of rocks accumulated. During the Eocene, according to the geologists of the Fortieth Parallel Survey, a great fresh-water lake occupied the Wasatch Mountain area, and toward the close of this epoch the mountains were finally uplifted and the relative depression of the Great Basin originated. The late Tertiary witnessed the formation of several lakes whose positions were determined by different crustal movements, and these lakes persisted with varying relations into the Pleistocene epoch. The end of Tertiary time was marked by further earth movements that divided the Great Basin area into two main depressions, following the bases of the recently uplifted Wasatch Mountains and the Sierra Nevada. In Quaternary time the bordering mountains were occupied by glaciers, and enormous lakes accumulated in the marginal depressions of the Great Basin. The two largest of these have been named after early explorers. Lake Lahontan covered an immense area in western Nevada and Lake Bonneville occupied a considerable part of western Utah and extended into adjacent parts of Nevada and Idaho.

QUATERNARY HISTORY.

The existence of Lake Bonneville is borne witness to by a number and variety of facts, chief of which are the remains of shore lines and shore deposits, and the great thickness of sediments that accumulated in the lake and that now constitute the valley floor. At its greatest extent the water of Lake Bonneville was approximately 1,000 feet above the present surface of Great Salt Lake. This large body of water abutted against the adjacent highlands and the outline of the lake was intricate. Deep bays and jutting promontories marked the shores, and lone mountains, partly submerged, stood out as islands.

The area considered in this report formed part of one of these bays. This—

> was divided by a close stricture into an outer bay and an inner, the outer covering the valley of the Jordan River and the inner spreading over Cedar, Utah, and Goshen valleys and a part of Juab Valley. In the inner bay the Goshen Hills made two islands, and the Pelican Hills constituted one large and several small islands. Small estuaries occupied Emigration and Little Cottonwood canyons, connecting with the outer bay, and the inner bay sent an estuary into Provo Canyon.[a]

[a] Gilbert, G. K., *Lake Bonneville*: Mon. U. S. Geol. Survey, vol. 1, 1890, p. 103.

During the existence of Lake Bonneville sedimentation was practically continuous in its lowest depression, but toward the periphery oscillations of the water level alternately covered the lake deposits and exposed them to subaerial influences. Evidence of the earliest Pleistocene history of the Bonneville region is furnished by alluvial cones that extend nearly to the bottom of the basin. These are composed of detritus derived from the adjacent highlands under subaerial conditions and could not have been accumulated when the level of the lake was high. It is therefore concluded that at this early period in the history of the lake comparatively arid conditions prevailed, for the stage of a lake in a closed basin is determined by the relation of evaporation to water supply. It has also been determined that at this period of the history of the lake it had no outlet and that the time of duration of low water was relatively long.

Next succeeded a period of high water, when yellow clay, locally streaked with sand, was deposited in a large part of the lake. The base of the yellow clay has not been observed and good sections are rare, though an exposure 150 feet thick has been measured. The deposit locally extends to within 120 feet of the highest level attained by Lake Bonneville, but a study of the shore line shows that during the deposition of the yellow clay the water did not rise to the rim of the basin. In the lower part of the basin the yellow clay is unconformably overlain by a deposit of white marl, local streaks of alluvium occurring at the contact. The white marl is composed of a fine calcareous clay consisting of calcium and magnesium carbonates, microscopic siliceous organic remains, and fine clastic débris.

These facts imply (1) that after the deposition of the yellow clay the lake water subsided, (2) that the clay was eroded, and (3) that a second period of high water subsequently ensued when the white marl was deposited. The extent to which the waters subsided is undetermined, but the possibility of complete desiccation is suggested by the difference in character between the yellow clay and white marl. The extent of the second period of high water is determined by the highest shore line traceable along the adjacent mountain flanks. This level is approximately 1,000 feet above Great Salt Lake and is known as the Bonneville shore line. The lake then outflowed through Cache Valley into the Snake River basin.

The Bonneville shore line marks the highest stage of Lake Bonneville and the level of its initial outflow. Beneath this level the drainage channel was cut down by the outflow of the lake to a depth of approximately 375 feet. That the lake maintained its level at the stage of lowest outflow for a relatively long time is attested by the well-developed shore phenomena at the corresponding elevation. This stage determined the Provo shore line, so named from its great development near that town.

The present conditions have been brought about by the recession of the lake's surface due to the excess of evaporation over inflow, so that now Great Salt, Utah, and Sevier lakes are the sole remnants of the former great body of water. The recession has uncovered the great expanse of lake beds that underlie the intermontane plains and constitute the fertile lands at the base of the Wasatch Mountains, and has also exposed the remarkable shore-phenomena that testify to the history of Lake Bonneville, so completely worked out by Gilbert.

The Bonneville basin is preeminently characterized by its many shore lines (Pl. III, *B*), the highest of which impinges against the mountains and the lowest of which that can be recognized incloses the area covered by the lake sediments. Through a vertical interval of 1,000 feet the story of the rise and fall of this body of water is recorded by the superposition of shore line upon lake sediment and of lake sediment upon shore line. The record is not in all cases perfectly legible, but the main features are unmistakable.

The work of waves is recorded by cliffs and wave-cut terraces, from which the débris was carried along the shore to make benches, bars, spits, and terraces. The streams loaded with the waste of the land areas deposited their burdens in the lake, the coarser detritus being laid down near shore while the finer sand and clay were carried far out before sedimentation occurred. Deltas were formed at the mouths of the larger creeks where so much débris was carried that the shore currents could not distribute it. Since the recession of

.1. NORTHERN END OF UTAH LAKE.

Oquirrh Mountains in background.

HEAD-GATE OF JORDAN AND SALT LAKE CITY CANAL, LOOKING SOUTH.

Embankment at point of the mountain in background.

PRECIPITATION.

Monthly and annual precipitation at Salt Lake City, 1875 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1875	3.05	0.79	2.81	1.50	2.91	0.90	1.01	0.25	1.22	1.36	5.81	2.03	23.64
1876	1.23	1.52	4.00	2.09	4.30	.09	.83	.92	.42	3.27	.81	1.80	21.28
1877	.87	.38	2.93	2.14	3.49	.80	.02	.28	.90	2.41	1.02	1.11	16.35
1878	1.07	3.49	2.54	2.63	2.50	.35	1.08	.81	3.15	1.39	.63	.11	19.75
1879	1.87	.71	.67	3.26	.10	1.34	.07	.06	.01	1.62	.32	3.08	13.11
1880	.29	1.02	.43	2.37	1.85	.01	.20	.74	.56	.40	1.17	1.90	10.94
1881	1.24	2.44	.88	2.37	2.55	.28	.21	1.61	.43	2.19	1.44	1.24	16.88
1882	1.50	.42	1.12	3.81	.26	2.24	.30	1.61	.37	2.89	.54	.92	15.98
1883	1.47	.72	1.75	2.92	.98	.33	.10	.62	.13	2.24	1.78	1.20	14.24
1884	.71	2.23	3.69	2.89	1.78	.33	.27	.73	1.91	.36	.50	2.12	17.52
1885	1.48	1.56	2.64	3.47	2.49	2.67	.58	.90	1.29	.59	3.10	.92	21.69
1886	1.91	1.36	2.60	4.43	.06	1.02	T.	.59	1.88	1.98	1.79	1.27	18.89
1887	2.36	1.41	.35	1.87	.73	.37	1.23	.69	.55	.30	.25	1.55	11.66
1888	1.52	1.22	2.18	.99	.34	.98	.24	.63	.51	.80	2.00	2.21	13.62
1889	.73	.81	1.64	1.52	2.97	.01	.08	.92	.52	3.85	4.04	4.37	18.46
1890	3.07	2.05	1.12	.94	.16	.32	.02	.79	T.	1.44	T.	.42	10.33
1891	.74	.76	4.66	1.49	.72	1.08	.47	.46	1.19	1.26	.90	2.19	15.92
1892	1.61	.68	2.21	1.90	1.65	1.21	T.	.05	.12	1.58	.72	2.35	14.08
1893	.82	1.64	2.68	2.72	1.68	.04	1.19	.71	1.30	1.02	1.18	2.37	17.35
1894	1.31	.83	1.73	1.67	1.22	1.38	.82	.87	2.87	1.01	.28	1.28	15.27
1895	1.32	.85	.81	.73	2.29	.99	.42	.02	.95	.24	2.44	.89	11.95
1896	1.26	.69	1.99	2.53	3.67	.25	1.35	1.47	.52	.70	3.15	.84	18.42
1897	1.16	3.81	2.20	2.00	.98	.52	.69	.33	.48	1.91	1.19	1.47	16.74
1898	.58	.38	1.71	1.30	4.19	1.45	.18	1.35	.15	1.57	1.95	1.28	16.09
1899	.84	2.98	2.93	.81	2.50	.96	.42	1.06	T.	2.85	1.52	.61	17.57
1900	.44	1.30	.33	2.91	.44	.08	.32	.72	1.44	1.99	1.40	.16	11.53
1901	.95	1.77	2.48	.87	4.27	.49	.31	1.22	.66	.98	.92	1.16	16.08
1902	.80	1.17	1.22	3.69	.33	.37	.56	.15	.05	.52	1.24	1.31	11.41
1903	2.11	.82	1.35	1.11	3.55	.74	.14	.43	.84	.81	2.21	.51	14.62
1904	1.45	2.25	3.99	2.20	3.08	.27	.59	.28	.12	1.18	.00	.90	16.31
Mean	1.44	1.33	2.03	2.21	1.62	.79	.53	.72	.93	1.54	1.36	1.64	16.19

Monthly and annual precipitation at Park City, 1899 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0.90	1.80	.....
1900	0.93	1.87	0.38	3.56	0.30	T.	0.10	0.32	2.23	0.90	3.50	1.30	15.30
1901	2.24	2.35	3.15	1.92	1.50	0.20	.90	1.40	.45	.18	1.40	2.20	17.80
1902	1.90	1.18	4.04	1.96	.67	.....	.....	.....	.....	.....	.....	.....	.....
1903	3.88	1.34	2.60	.95	2.89	T.	.....	.....	.92	.30	.55	.95	.....
1904	2.15	5.00	7.85	1.69	2.44	.....	.....	1.99	.....	.....	.00	.....	.....

Monthly and annual precipitation at Provo, 1899 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
9	1.54	2.89	2.45	0.39	1.37	.....	.....	.....	0.00	2.79	0.94	1.05	.....
0	.45	35	05	1.65	.32	.....	.....	.....	1.13	.66	3.50	.12	.....
1	.22	2.06	1.09	.29	.39	0.18	T.	.....	.....	T.	.85	.98	.....
2	.35	12	1.30	2.14	.36	.10	0.11	0.20	.....	.68	1.55	1.28	.....
3	2.65	65	1.80	.51	2.69	.30	.39	.42	.72	.55	1.14	.49	12.31
4	1.72	2.27	3.75	1.56	2.11	.42	.39	.45	.04	1.56	.00	1.05	15.32

Monthly and annual precipitation at Heber, 1899 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
899	2.95	5.85	3.00	0.89	1.14	0.97	1.61	2.10	0.15	3.20	0.85	1.55	14.26
900	1.06	1.50	.34	2.53	.16	.20	.25	.31	1.20	1.47	4.42	.22	13.66
901	2.20	2.20	1.56	.31	1.72	.08	.40	2.06	.16	1.70	1.40	1.50	15.29
902	.50	1.03	1.46	1.88	.49	.37	.15	.50	.45	.45	1.77	1.04	10.09
903	2.17	.07	1.95	.78	1.42	.25	.69	.02	1.17	.76	1.90	1.33	13.32
904	2.10	3.00	3.48	.96	2.01	.73	.29	.88	.16	1.22	.00	1.91	16.74

Monthly and annual precipitation at Thistle, 1899 to 1904.

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
899	1.60	2.40	1.30	0.05	0.88	T.	.....	.....	.....	0.40	2.08	.....	.....
900	.30	.47	.00	1.77	.05	0.10	0.10	0.46	1.00	.75	1.80	0.30	7.10
901	.....	2.35	2.40	1.15	.85	.05	.11	3.05	.25	1.15	.93	2.00	.....
902	1.90	2.05	2.00	2.23	.35	.00	.35	.20	.85	.41	2.10	1.45	13.89
903	.....	.....	.....	1.75	1.60	.35	.53	.10	.66	1.43	.80	1.40	.....
904	1.90	1.55	.....	.90	2.65	.....	.32	.46	1.90	.27	.00	1.50	.....

TEMPERATURE.

Mean monthly and annual temperature at Salt Lake City, 1873 to 1904.

	° F.		° F.
anuary	27.9	August	74.8
ebruary	33.0	September	64.3
larch	41.6	October	52.3
pril	49.5	November	39.8
lay	57.8	December	32.7
une	67.0		
uly	75.5	Annual	51.4

Mean monthly and annual temperature at Provo, 1890 to 1904.

	° F.		° F.
January	26.6	August	70.7
February	29.3	September	59.8
March	39.3	October	48.7
April	49.1	November	38.4
May	58.0	December	29.2
June	64.7		
July	73.2	Annual	49.2

Monthly maximum temperature at Salt Lake City, 1899 to 1904.

[° F.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1899	54	51	67	80	83	96	97	91	91	73	63	59
1900	57	55	72	78	89	101	99	94	88	76	68	56
1901	51	55	65	79	88	90	101	95	86	85	67	59
1902	43	62	58	78	88	98	96	98	92	81	70	58
1903	53	42	65	80	86	91	96	98	92	77	70	46
1904	48	66	63	78	83	92	97	94	92	83	66	55
Mean	51	55	65	79	86	95	98	95	90	79	67	55

Monthly minimum temperature at Salt Lake City, 1899 to 1904.

[° F.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1899	16	−10	20	30	25	34	51	46	46	30	28	9
1900	20	10	26	30	40	47	53	52	32	27	28	2
1901	4	15	25	15	43	40	49	56	39	36	29	11
1902	− 4	12	21	32	35	42	43	52	35	36	21	15
1903	15	− 4	14	25	33	54	46	48	37	32	17	14
1904	7	6	19	30	36	44	51	46	38	28	26	7
Mean	11	10	21	27	35	44	49	50	38	32	25	10

WIND VELOCITY.

Average wind velocity at Salt Lake City, 1900 to 1904.

[Miles per hour.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900	3.4	5.2	6.3	7.3	6.8	6.5	6.0	6.4	6.5	6.5	5.0	4.5	5.9
1901	5.0	4.0	6.2	7.8	7.3	6.6	6.3	5.8	7.0	5.0	4.9	4.8	5.9
1902	3.8	5.5	6.9	6.7	7.1	6.7	6.7	6.5	6.7	5.7	6.0	4.7	6.1
1903	4.8	4.5	6.8	7.3	6.1	6.6	7.2	6.2	6.3	5.3	5.4	3.7	5.8
1904	4.1	6.3	7.3	7.2	6.8	6.5	6.5	5.7	6.0	5.4	4.7	4.9	6.0
Mean	4.2	5.1	6.7	7.2	6.8	7.0	6.5	6.1	6.5	5.6	5.2	4.5	5.9

HUMIDITY.

Mean relative humidity at Salt Lake City, 1900 to 1904.

[Per cent.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900	78	65	40	59	41	25	24	24	36	48	62	63	47
1901	69	73	55	42	44	36	26	39	30	50	57	71	49
1902	83	62	58	48	43	31	27	27	32	40	56	65	48
1903	73	74	52	44	48	38	30	28	38	45	64	75	51
1904	75	62	64	46	49	38	33	38	34	53	45	60	50
Mean	76	67	54	48	45	34	28	31	34	47	57	67	49

EVAPORATION.

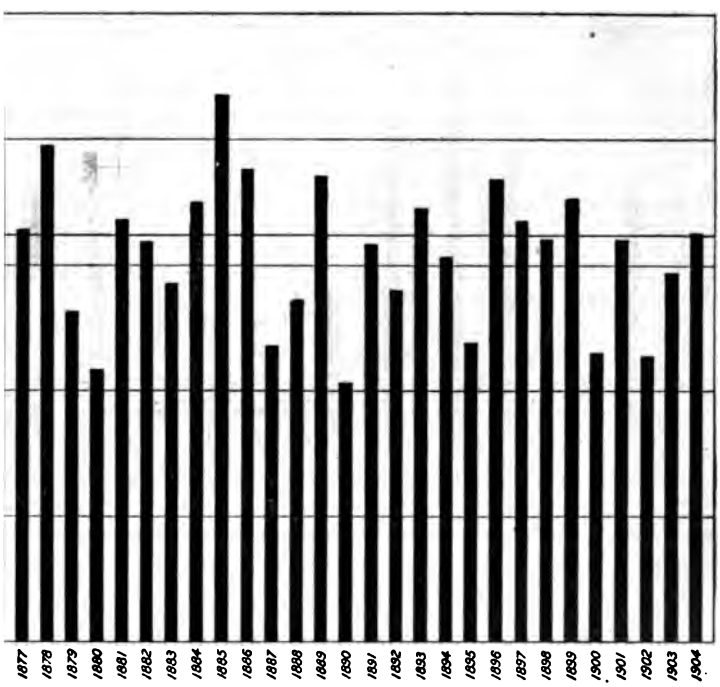
pth of evaporation at Utah Lake [a] *from August, 1903, to August, 1904.*

[Inches.]

1903.		1904—Continued.	
.....	8.40	February.....	2.00
.....	6.78	March.....	3.50
.....	3.86	April.....	4.63
.....	2.50	May.....	7.72
.....	1.50	June.....	8.80
1904.		July.....	9.41
.....	1.50	Total.....	60.60

SUMMARY.

te of the valleys of Utah Lake and Jordan River is controlled by their location
l eastern part of the Great Basin, but is modified somewhat by the proximity



G. 1.—Diagram showing variation of annual precipitation at Salt Lake City.

l Great Salt Lakes and the Wasatch Mountains. The tables show that the haracterized by low annual precipitation, moderate temperature, moderate y, low relative humidity, and considerable evaporation.

annual precipitation at Salt Lake City is 16.19 inches, ranging between a maxi- 4 inches in 1875 and a minimum of 10.33 inches in 1890. Since 1900 it has 2 inches below normal (fig. 1). Only about 18 per cent of the annual total

from daily measurements of a tank 3 feet in diameter. Tests were made by the engi- ake City from 1901 to 1903, and since then they have been kept up by the Reclamation G. L. Swendsen. See also Newell, F. H., Fourteenth Ann. Rept. U. S. Geol. Survey, 54.

occurs from June to September, and for these four months amounts to less than 3 inches. Between October and May the variation is not marked, but the greatest precipitation occurs in March and April (fig. 2). This precipitation is unusually high for the Great Basin. The Wasatch Mountains serve to condense the moisture, originally derived in large part from the westerly winds from the Pacific Ocean, that remains in the air after crossing the Sierra Nevada.

Probably the precipitation is greater on the summits than at the stations where records have been kept, but data are not available. The melting snow of the winter's accumulation is the chief supply of the streams of the area under consideration.

The mean annual temperature of Salt Lake City is 51.4°. The mean monthly maximum ranges from 98° in July to 51° in January, while the mean monthly minimum varies between 10° in December and February and 50° in August.

The dryness of the atmosphere is indicated by the mean relative humidity of 49 per cent, varying from 28 per cent in July to 76 per cent in January, and by the amount of evaporation from a free water surface, which, according to the latest measurements, is about 60

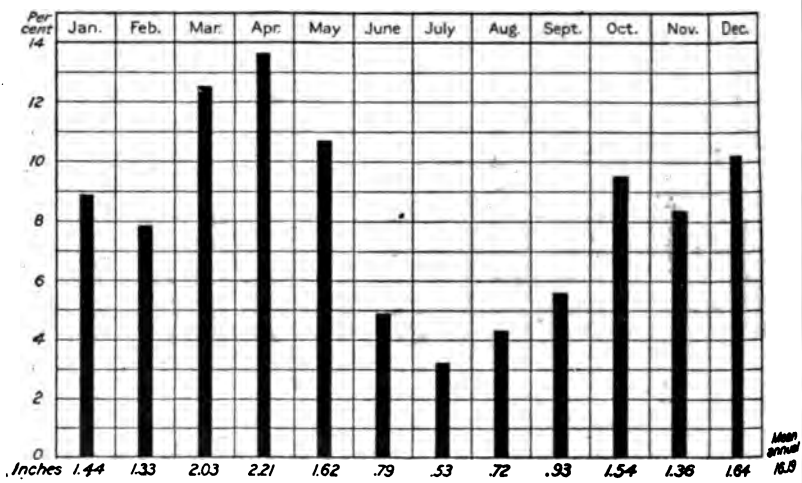


FIG. 2.—Diagram showing mean monthly precipitation at Salt Lake City.

inches a year. Yet the climate is not nearly as dry as in other parts of the Great Basin. The dryness lessens the effect of the summer's heat, so that the "sensible temperature" is not so great as would be suggested by the thermometer, being modified by the cooling effects of evaporation.

HYDROGRAPHY.

STREAMS TRIBUTARY TO UTAH LAKE AND JORDAN RIVER.

Seepage from surface streams, as shown hereafter, is the most important source of supply of underground water in the valleys of Utah Lake and Jordan River. A summary of discharge measurements therefore throws important light on the subject and, with other data, furnishes facts for roughly estimating the amount of water available for the annual replenishment of the underground reservoirs. The figures here given have been compiled from records of the United States Geological Survey and from data obtained through the courtesy of the city engineer of Salt Lake City, and are now published for the first time.

Satisfactory measurements of the flow of all the streams in the two valleys have not been made. However, records have been kept for a number of years of the discharge of several of the more important, and the combined data, with due consideration for varying conditions, may be taken as typical of the drainage of the entire watershed. The measure-

made at the mouths of the canyons. Below these points, during the irrigation water is diverted and conducted over the valley in an intricate system of that the stream beds in their lower stretches are then often dry. During the n the streams discharge directly into either Utah Lake or Jordan River. Fol- tables of monthly measurements for 1904, to which annual summaries for several dded where figures are available:

lischarge (at mouths of canyons) of streams tributary to Jordan River and Utah Lake.

CITY CREEK.

[Drainage area, 19 square miles.]

	Discharge.			Total.	Run-off.			Rainfall.a
	Maximum.	Minimum.	Mean.		Per square mile.	Depth.	Relation to rainfall.	
	Sec.-feet.	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*	*Per cent.*	*Inches.*
.....	6.7	6.0	6.2	381	0.326	0.376	20.9	1.80
.....	7.9	6.0	6.6	380	.347	.374	10.3	3.62
.....	11.0	7.3	8.1	516	.442	.510	8.6	5.92
.....	28.8	11.0	22.1	1,315	1.160	1.294	66.7	1.94
.....	70.1	28.8	55.6	3,419	2.926	3.373	122.2	2.76
.....	57.0	26.6	39.2	2,332	2.063	2.301	852.2	.27
.....	26.5	16.2	19.7	1,211	1.037	1.195	202.5	.59
.....	15.3	11.5	13.4	824	.705	.813	71.9	1.13
.....	11.4	9.4	10.4	619	.547	.610	508.3	.12
.....	9.3	8.7	9.1	609	.479	.551	46.7	1.18
.....	8.7	8.2	8.5	506	.447	.499	.....	.00
.....	9.2	7.7	8.0	492	.421	.485	53.9	.90
.....	70.1	6.0	17.2	12,604	.908	12.381	61.2	20.23
.....	63.1	4.3	13.0	9,440	.685	9.323	63.1	14.77
.....	58.2	3.6	12.3	8,910	.647	8.811	69.5	12.67
.....	72.0	5.0	12.7	9,251	.668	9.126	53.9	16.94
.....	31.3	5.4	9.8	7,054	.517	7.040	52.5	13.41
.....	121.9	3.2	20.0	14,491	1.053	14.306	80.1	17.85

EMIGRATION CREEK.

[Drainage area, 19 square miles.]

.....	6.3	0.7	1.1	68	0.058	0.069	2.3	2.99
.....	.8	.5	.6	33	.032	.033	3.1	1.08
.....	11.7	.4	3.0	184	.158	.182	9.2	1.97
.....	12.8	3.7	8.0	476	.421	.470	45.6	1.03
.....	19.3	5.5	9.5	584	.500	.576	17.9	3.22
.....	18.1	4.0	8.6	512	.453	.505	136.5	.37
.....	4.0	1.6	2.8	172	.147	.169	120.7	.14
.....	1.7	.6	1.0	61	.053	.061	14.2	.43
.....	1.1	.6	.8	48	.042	.047	5.3	.88
.....	2.0	1.1	1.2	74	.063	.073	13.3	.55
.....	3.2	1.0	1.3	77	.068	.076	5.5	1.38
.....	.8	.6	.7	43	.037	.043	5.9	.73
.....	19.3	.4	3.2	2,332	.169	2.304	15.6	14.77

d of rainfall given under City, Emigration, Parleys, and Mill creeks is the mean precipita- Lake City and Park City; that under American Fork and Provo River is for Provo and under Spanish Fork is for Provo, Thistle, and Soldiers Summit.

Estimated discharge (at mouths of canyons) of streams tributary to Jordan River and Lake—Continued.

PARLEYS CREEK.

[Drainage area, 50 square miles.]

Date.	Discharge.			Total.	Run-off.			Ra
	Maximum.	Minimum.	Mean.		Per square mile.	Depth.	Relation to rainfall.	
1904.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*	*Per cent.*	*In*
January	9.2	4.8	7.1	437	0.142	0.164	9.0	
February	18.1	4.2	10.3	592	.206	.222	6.1	
March	39.3	9.4	19.6	1,205	.392	.452	7.6	
April	207.3	69.8	123.2	7,331	2.464	2.749	141.8	
May	208.5	88.1	168.5	10,361	3.370	3.886	140.8	
June	137.5	28.5	52.6	3,130	1.052	1.174	434.8	
July	41.1	19.5	26.1	1,605	.522	.602	102.0	
August	20.2	11.8	16.0	984	.320	.369	32.7	
September	13.0	9.4	11.4	679	.228	.254	211.7	
October	13.7	11.8	12.9	793	.258	.297	25.2	
November	11.8	8.8	10.3	613	.206	.230	.....	
December	10.8	2.5	8.3	510	.166	.191	21.2	
Year	208.5	2.5	38.9	28,240	.777	10.590	52.3	
1903	133.7	2.1	20.5	14,879	.410	5.581	37.8	
1902	95.3	2.2	16.7	12,116	.334	4.544	35.9	
1901	109.5	3.0	19.9	14,490	.398	5.429	32.0	
1900	39.0	2.9	12.6	9,0[illegible]8	.251	3.431	25.6	
1899	227.5	4.0	59.8	39,722	1.196	14.884	83.4	

MILL CREEK.

[Drainage area, 21 square miles.]

1904.								
January	13.0	6.6	9.9	609	0.471	0.543	30.2	
February	13.0	3.7	9.9	569	.471	.508	14.0	
March	13.0	9.3	11.2	689	.486	.560	9.4	
April	25.1	11.3	18.8	1,120	.895	.999	51.5	
May	58.2	25.1	41.4	2,545	1.971	2.272	82.3	
June	55.9	29.7	40.9	2,434	1.948	2.173	804.8	
July	29.7	20.8	25.7	1,580	1.224	1.411	239.2	
August	16.8	13.0	14.9	916	.710	.819	72.5	
September	15.9	13.0	15.0	893	.714	.797	664.2	
October	14.0	13.0	13.7	842	.652	.752	63.7	
November	13.0	11.3	12.4	738	.590	.658	.....	
December	11.3	1.0	8.6	529	.410	.473	52.5	
Year	58.2	1.0	18.5	13,464	.878	11.965	59.1	
1903	34.4	2.9	12.3	8,916	.586	7.964	53.9	
1902	39.5	1.9	12.1	8,753	.575	7.814	61.7	
1901	47.4	1.4	12.9	9,391	.615	8.383	49.5	
1900	30.8	1.4	11.5	8,296	.549	7.466	55.7	
1899	66.0	2.4	19.6	14,193	.932	12.669	77.1	

d discharge (at mouths of canyons) of streams tributary to Jordan River and Utah Lake—Continued.

BIG COTTONWOOD CREEK.

[Drainage area, 48 square miles.]

ate.	Discharge.			Total.	Run-off.			Rainfall.
	Maximum.	Minimum.	Mean.		Per square mile.	Depth.	Relation to rainfall.	
902.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*	*Per cent.*	*Inches.*
.....	27.6	13.6	23.1	1,421	0.481	0.555	.....	.....
.....	28.4	17.2	24.2	1,344	.504	.525	.....	.....
.....	27.7	20.4	24.6	1,513	.512	.590	.....	.....
.....	142.9	27.0	70.4	4,189	1.470	1.640	.....	.....
.....	369.7	108.9	210.2	12,925	4.380	5.050	.....	.....
.....	309.5	91.7	194.5	11,574	4.050	4.519	.....	.....
.....	92.3	40.9	62.2	3,825	1.300	1.499	.....	.....
.....	38.9	28.4	33.0	2,029	.688	.793	.....	.....
er.....	31.6	25.2	27.9	1,661	.581	.648	.....	.....
.....	29.0	21.4	26.3	1,617	.548	.632	.....	.....
er.....	28.8	21.8	24.8	1,476	.517	.577	.....	.....
r.....	29.3	16.1	22.8	1,402	.475	.548	.....	.....
ar.....	369.7	13.6	62.0	44,976	1.292	17.576	.....	.....
.....	407.3	11.3	68.3	49,639	1.422	19.381	.....	.....

AMERICAN FORK.

[Drainage area, 66 square miles.]

904.								
.....	17	15	16.1	990	0.244	0.281	14.7	1.91
.....	16	15	15.4	886	.233	.251	9.5	2.64
.....	24	15	19.1	1,174	.289	.333	9.2	3.62
.....	109	23	46.9	2,791	.711	.793	63.0	1.26
.....	379	95	216.0	13,280	3.27	3.77	183.0	2.06
.....	310	131	201.0	11,960	3.05	3.40	596.0	.57
.....	147	66	95.3	5,860	1.44	1.66	488.0	.34
.....	64	44	52.8	3,247	.800	.922	140.0	.66
er.....	43	35	38.1	2,267	.577	.644	644.0	.10
.....	41	34	35.9	2,207	.544	.627	45.1	1.39
er.....	34	28	30.0	1,785	.454	.507	.....	.00
r.....	28	18	25.3	1,556	.383	.442	29.8	1.48
ar.....	379	15	66.0	48,000	1.00	13.62	85.0	16.03

Estimated discharge (at mouths of canyons) of streams tributary to Jordan River and Utah Lake—Continued.

PROVO RIVER.

[Drainage area, 640 square miles.]

Date.	Discharge.			Total.	Run-off.			Rainfall.
	Maximum.	Minimum.	Mean.		Per square mile.	Depth.	Relation to rainfall.	
1904.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*	*Per cent.*	*Inches.*
January	290	196	244	15,000	0.381	0.439	23	1.91
February	861	253	373	21,460	.583	.629	24	2.64
March	667	331	388	23,860	.606	.699	19	3.62
April	680	353	486	28,920	.759	.847	67	1.26
May	2,153	461	1,145	70,410	1.79	2.06	100	2.06
June	1,625	371	1,131	67,300	1.77	1.98	347	.57
July	326	136	202	12,420	.316	.364	107	.34
August	182	134	149	9,162	.233	.269	41	.66
September	184	80	117	6,962	.183	.204	204	.10
October	146	79	113	6,948	.177	.204	15	1.39
November	190	113	139	8,271	.217	.242	.....	.00
December	205	113	149	9,162	.233	.269	18	1.48
Year	2,153	79	386	279,900	.604	8.20	51	16.03
1898	1,212	146	386	279,000	.60	8.19	49	16.71
1897	2,600	225	[a] 571	414,000	.89	12.12	68	17.76
1895	1,760	192	423	306,400	.66	9.07	62	[a] 14.63

[a] Approximate.

SPANISH FORK.

[Drainage area, 670 square miles.]

1904.								
January	113	58	77.6	4,771	0.116	0.134	8.1	1.66
February	126	58	79.1	4,550	.118	.127	7.4	1.71
March	240	63	85.8	5,276	.128	.148	4.4	3.36
April	229	110	174.0	10,350	.260	.290	28.0	1.02
May	415	236	343.0	21,090	.512	.590	25.0	2.33
June	255	111	162.0	9,640	.242	.270	41.0	.66
July	121	80	94.6	5,817	.141	.163	39.0	.42
August	92	67	75.8	4,661	.113	.130	19.0	.69
September	75	65	68.0	4,046	.101	.113	13.0	.85
October	69	65	67.8	4,169	.101	.116	11.0	1.01
November	69	49	61.5	3,660	.092	.102	.....	.00
December	77	40	54.3	3,339	.081	.093	8.7	1.07
Year	415	40	112.0	81,370	.167	2.28	15.4	14.78

Comparison of the discharge of several streams shows marked differences. For instance, during 1901 and 1902, the only years when complete measurements of both Parleys and Big Cottonwood creeks are available, the discharge of Big Cottonwood (drainage area, 48 square miles) averaged 47,308 acre-feet, while that of Parleys, with a drainage area slightly greater (50 square miles), averaged only 13,303 acre-feet. Again, during 1904 the discharge of City and Emigration creeks, each having drainage areas of approximately 19 square miles, amounted, respectively, to 12,604 and 2,332 acre-feet. Provo and Spanish *Fork rivers also affor* ts. The drainage area of Provo River (640 square miles)

is slightly less than that of Spanish Fork (670 square miles), yet the discharge of the former in 1904 was more than three times that of the latter.

It will be noticed that the flows of Spanish Fork and of Emigration Creek, streams which in the above comparisons figured poorly, have much in common, though their drainage areas differ greatly. The flow of the two streams, expressed in second-feet per square mile of their drainage areas, averaged 0.167 for Spanish Fork and 0.169 for Emigration Creek, which may be compared with an average of 0.746 for City Creek and 0.69 for Provo River. The amount of discharge, expressed in depth of inches, over the watershed is 2.28 for Spanish Fork 2.30 for Emigration Creek, and 10.33 for City Creek. The run-off is approximately 15 per cent of the precipitation for Spanish Fork and Emigration Creek, and about 63 per cent for City Creek.

These and other discrepancies are due to a complex set of causes, chief of which are differences in precipitation, topography, vegetation, soils, and rocks of the several drainage areas, and the care that is taken to prevent fires, grazing, and destruction of timber on the watersheds. Though in general the main streams in the Wasatch Mountains have many features in common, the valleys of some of them are narrow and steep, while those of others are broader and more open. Some valleys are better adapted than others, by configuration and position, to collect and keep snow. Some of the streams head in lakes, while others do not. All are poorly clothed with trees, but some are less fortunate in this respect than others. The soil covering in general is thin, particularly on the steep slopes and in areas where the absence of much vegetation allows the products of rock disintegration to be washed into the valleys. But where the slopes are comparatively gentle and vegetation protects the accumulated rock débris, more of the precipitation is absorbed and (escaping flood discharge) seeps slowly into the valleys to maintain the perennial flow of the streams. Differences in the porosity of the bed rocks and in the character and quantity of débris in the stream beds, whereby greater or less amounts of water are absorbed, also greatly influence the amount of run-off.

UTAH LAKE.

Utah Lake is fed from several sources, including surface streams, seepage, springs beneath the lake, and the precipitation that falls upon it. The measurable factors were determined

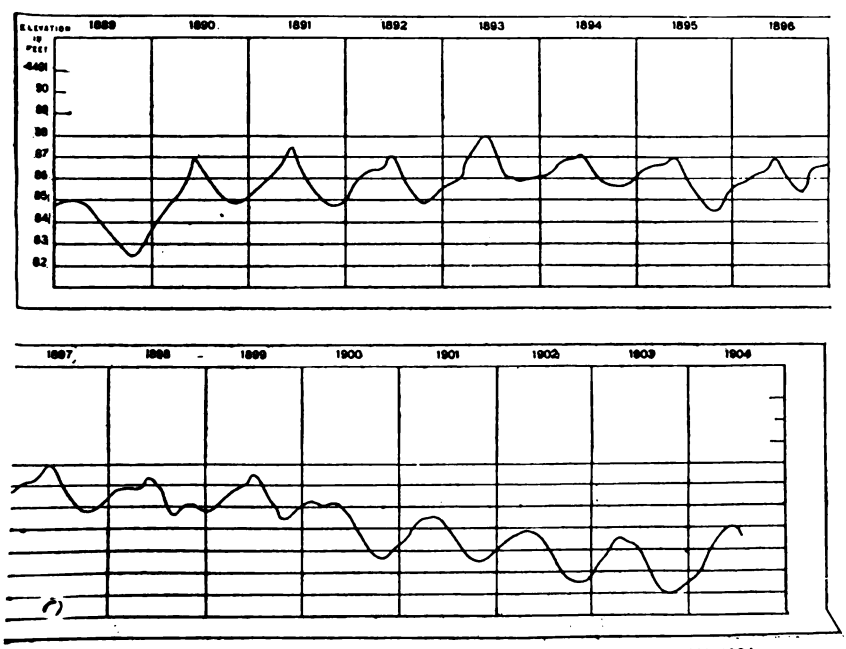


Fig. 3.—Diagram showing fluctuations of the surface of Utah Lake, 1889–1904.

for the period August 1903, to August, 1904, under the direction of G. L. Swendsen,[a] of the United States Reclamation Service, who found that of the total supply of 604,010 acre-feet only 471,140 were contributed by rainfall on the lake and by the measurable surface streams, leaving an unmeasured supply of 132,870 acre-feet. This considerable amount appears to be contributed by seepage and by springs, some of which have recently been found in the northwestern part of the lake.

The surface of the lake is subject to considerable variation in elevation in consequence of the changing relations of evaporation, precipitation, inflow, and outflow. Fig. 3, prepared by the Reclamation Service, shows fluctuations of the surface from 1889 to 1904.

There is a seasonal variation of 1 to 4 feet, ranging from a minimum in the late fall to a maximum in late spring and early summer. The diagram also shows the variation in the mean level of the lake. The lowest elevation shown occurred in 1903, when the lake was about half a foot lower than it was in 1889. Following 1889 was a period of ten years of relatively high water.

JORDAN RIVER.

During the last few years anomalous conditions have existed at the outlet of Utah Lake. The water level of the lake has fallen so low that the normal flow has ceased, and in order to supply the canals in Jordan Valley it has been necessary to resort to pumping. Accordingly a pumping plant has been in operation at the head of Jordan River since August, 1902. (Pl. IV, *A*.)

The following table of discharges has been prepared by Mr. J. Fewson Smith, jr., water commissioner:

Discharge of Jordan River and the canal systems in Jordan Narrows, and of Jordan River at pumping plant, April to October, 1904.

[Acre-feet.]

Month.	North Jordan.	East Jordan.	City	South Jordan.	Utah and Salt Lake.	Jordan River at weir.	Sum of preceding.	Jordan River at pumping plant.[a]
1904.								
April	.....	650	.....	647	720	75	2,092	222
May	903	3,036	596	5,167	4,150	2,911	16,823	18,090
June	2,970	5,701	452	6,648	7,878	4,225	27,874	25,110
July	3,384	5,369	3,199	5,407	6,719	3,894	27,972	25,210
August	3,233	5,186	3,090	5,031	7,110	3,668	27,318	24,720
September	2,662	5,280	1,373	5,357	7,992	2,767	25,431	23,330
October	753	1,920	399	2,134	3,367	310	8,883	8,363
Total	13,965	27,142	9,109	30,391	37,936	17,850	136,393	125,045

[a] Figures furnished by G. L. Swendsen.

From these figures it appears that the gain in the flow of Jordan River between the pumping plant and the intake of the canals in Jordan Narrows, a distance of about 13 miles, April to October, 1904, was 11,348 acre-feet. The gain is partly supplied by seepage and partly by the flow of wells and springs. Between Jordan Narrows and the head of North Jordan canal, a distance of about 9 miles, Mr. J. Fewson Smith, jr., found that the seepage into Jordan River between May and September, 1904, amounted to 13,789 acre-feet.

[a] The writer acknowledges his indebtedness to Mr. Swendsen for many courtesies extended, both in the field and office, during the prosecution of the work.

A. GATE AT HEAD OF JORDAN RIVER.

B DEAD MAN'S FALLS, COTTONWOOD CANYON.

ɔ systematic data have been collected below the head of North Jordan canal, but in ·mber, 1904, the following measurements were made by Mr. Caleb Tanner and the er:

harge of Jordan River and tributaries between Little Cottonwood Creek and the ford, in sec. 4, T. 1 N., R. 1 W., December 6–7, 1904.

		Second-feet.
lan River above mouth of Little Cottonwood Creek		61.38
le Cottonwood Creek		8.14
me at Taylorville roller mill		39.0
Cottonwood Creek		51.2
ch south of Mill Creek		2.12
Creek		23.94
ch, outlet of Decker Lake		2.93
leys Creek, north and south ditches		8.78
hth South street ditch		6.09
Total		203.58
lan River below North Temple Street Bridge	190.22	190.22
Loss between mouth of Little Cottonwood Creek and North Temple street		13.36
let of Hot Springs Lake	7.64	
er ditch (estimate)	7.50	
lan River at ford, sec. 4, T. 1 N., R. 1 W		214.00
Total	205.36	205.36
Gain between North Temple Street Bridge and ford		8.64

.oss in the flow of Jordan River, instead of expected gain, is thus shown between the uth of Little Cottonwood Creek and North Temple Street Bridge at the time the measure- nts were made, while a slight gain is shown between the bridge and the ford in sec. 4, T. ·., R. 1 W. It appears that the seepage drains into the tributaries rather than directly into dan River in the area where the tributary streams are numerous and that farther north, ere there are fewer tributaries, a small amount of seepage drains directly into the river. w far these figures represent conditions the year round remains to be determined.

GREAT SALT LAKE.

Except during a lapse from 1893 to 1896, instrumental records of the surface fluctua- ı of Great Salt Lake have been kept since 1875, and there is evidence less exact dating k to the survey of the lake by Stansbury in 1849–50. When that survey was made the el of the lake was extremely low, and since then it has varied considerably. In 1869 water surface was approximately 11 feet higher than it was in 1850; a comparatively stage was reached in 1873, after which the lake rose about 4 feet to a maximum in 6, about equal to that attained in 1869. In 1883 the lake was about 7 feet below the ximum; then it rose 4 feet until 1886, since when it has gradually fallen until now it is ın extremely low stage, about 15 feet lower than the maxima of 1869 and 1876. Fig. lustrates the changes since 1875.

Besides the irregular fluctuations there is a regular annual variation ranging between 1 l 2 feet, the maximum occurring in June and the minimum in the winter This annual iation is due to the changing relations of precipitation, inflow, and evaporation, high ter occurring after the spring floods, and low water during the season of feeble stream dis- ırge and after the period of excessive evaporation. The irregular variation of the it can be accounted for chiefly by changes in rainfall, the earlier maxima being associ- d with unusually large amounts of precipitation. The gradual decrease of late years the volume of the lake, after allowing for recent dry seasons, is apparently due to gely increased *irrigation*, by which the inflow of surface streams has been checked

through diversion into ditches. Because of the considerable evaporation and transpiration incident to such use of the water, only a small per cent of the run-off reaches the

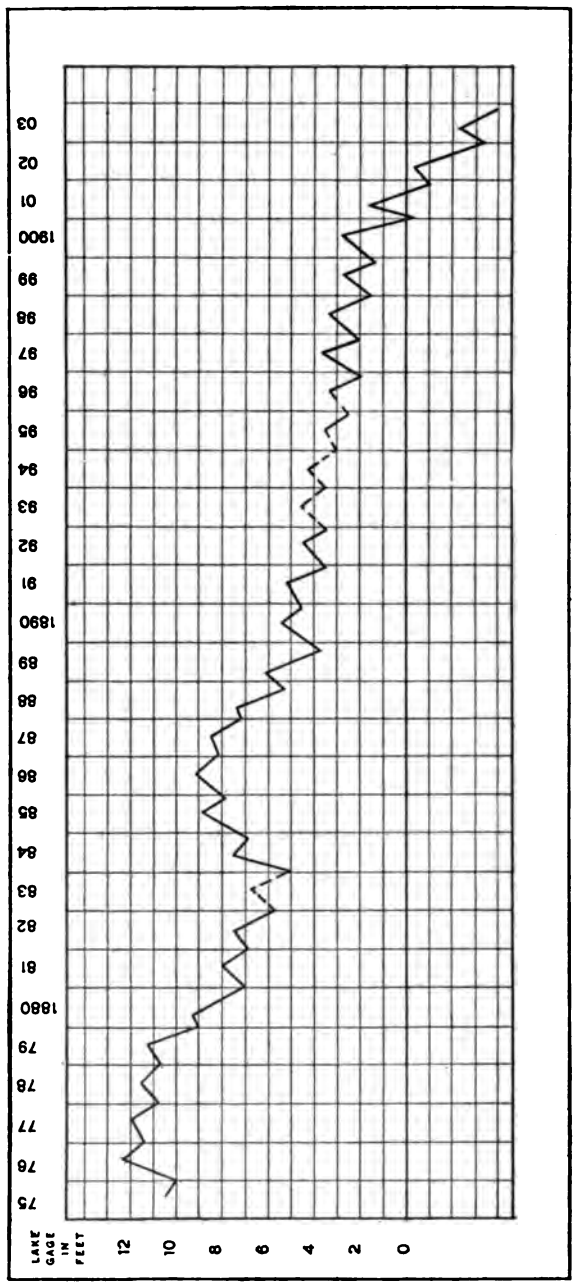


FIG. 4.—Diagram showing fluctuations of the surface of Great Salt Lake 1873-1903.

lake, and with the spread of irrigation it may be expected that this cause will increasingly *tend to* keep the lake level at a low stage.

UNDERGROUND WATER.

GENERAL CONDITIONS.

SOURCE.

ground water supply in the valleys of Utah Lake and Jordan River, as is well aintained by the snow and rain that fall on their drainage areas. In consid- ırces of the supply, the precipitation tributary to Utah Lake and Jordan River ·ntly be divided into that on the mountains and that on the main valley.

n stated that the actual precipitation in the mountains probably exceeds the vn by the recorded data. Moreover, neither the rainfall nor the snowfall is buted. The precipitation is greater in the northern than in the southern half ınder consideration, and in contiguous localities there are differences due to graphic conditions. More precipitation is likely to occur in the vicinity of the , and in the mountain recesses that are well protected from the sun large quan- ɾ linger long after the general mantle has disappeared.

ıl precipitation on the mountains, part is evaporated, part joins the run-off, and s underground water. Evaporation occurs either directly—from snow, from e of water, and from water contained in soils and brought to the surface by ion—or indirectly by transpiration through the growth of plants. Of the por- ›ins the run-off part runs directly out of the mountains, part flows to small head of Big Cottonwood Creek and Provo River, and part is absorbed by the s over which the streams flow and joins the subterranean store. A final portion itation on the mountains becomes underground water directly by absorption :e on which the rainfall occurs. Part of this underground water reaches the , by capillary action in the soils and by the life activity of plants and is finally another part after remaining underground a shorter or longer time reaches gain by springs and seepage, and, joining the run-off little by little, maintains the v of the streams; another part joins the more permanent supply of underground impossible, because of the complexity of the subject and the lack of data, to ıount of water which annually replenishes this more permanent supply of water, but the quantity is equivalent to the precipitation minus the run-off ınt evaporated. From the incomplete facts at hand it appears that the run-off, the mouths of the canyons, although varying greatly, approximates 50 per cent itation, but the total evaporation is unknown. Although exact figures repre- amount evaporated can not be obtained, yet experiments on evaporation from .nd vegetation in the mountain areas would afford valuable data.

ıt of precipitation in the valley is better known, and the figures for Salt Lake vo are typical. Here, as in the mountains, part of the precipitation joins the is evaporated, and part becomes underground water; but there are practi- ısurements of these different quantities. Direct run-off of the precipitation · is comparatively small, owing to the open nature of the country and to the great accumulations of snow occur, and the seepage run-off probably consti- ·in amount. Evaporation from soils and vegetation dissipates probably the ·f the rain that falls on the valley, especially during the summer. The increase ɔermanent underground water supply due to the rainfall on the valley is con- ıall. A basis for judgment is furnished by comparing the condition of the nd west of Jordan River. Precipitation is perhaps slightly less in the western ·lley, but the difference is not enough to cause the marked contrast. The scarc- l water within easy reach of the surface in the western part of the valley, com- ıe abundance easily accessible in the eastern part, implies that the rainfall on ntributes a proportionally small amount to the store of underground water. ditions are due to the fact that on the west only a few feeble and generally streams are tributary to the valley, whereas on the east a number of large *eams flow from the Wasatch* Mountains, supplying water that is distributed

over the valley by canals. Seepage from these streams is the main source of undergr supply in the valleys.

The amount of water contributed to the valleys by streams from the Wasatch Moun is capable of rough numerical statement. The drainage area in these mountains trib to Jordan Valley is approximately 220 square miles, and measurements of five creeks ir region, given in the section devoted to hydrography, show an average flow of 0.66 se foot per square mile of watershed. This amount is equivalent to a stream dischargi second-feet, or a total amount approximating 105,000 acre-feet a year. The aver measurements of Provo River and Spanish Fork in Utah Lake Valley gives a flow o second-foot per square mile of drainage area, which, assuming the flow to be derived rainfall on a watershed of about 1,670 square miles, is equivalent to a stream dischargi second-feet, amounting to 520,000 acre-feet a year.

Of this amount of water annually contributed by streams to the valleys of Utah and Jordan River, part permanently runs off and is added to the supply of Great Sal by Jordan River. This quantity has not yet been systematically measured, but it i mated to average about 200 second-feet. The residue either evaporates, directly an rectly, or becomes underground water. Unfortunately, no figures are available wl the amount lost by evaporation can be estimated, so that the annual replenishment underground supply is unknown. Only the crude statement can now be made that, presence of influences sufficient to cause an evaporation of 60 inches a year from a fre of water, the amount which is not thus lost from a supply of somewhat more th second-feet joins the underground store.

Seepage measurements which have been made at different times in both valley creeks and ditches offer concrete demonstrations of the manner in which the underg supply is maintained. Only a few such measurements have been made in Utah Lake but it has been shown that in 1½ miles the Timpanogas canal lost slightly more than cent of the water taken in at its head.[a] Another set of measurements has been ma Provo River. The discharge a short distance above the mouth of the canyon was fo be 175.04 second-feet; at a station a mile west of Provo the river was dry, whi sum of several intermediate diversions amounted to 186.22 second-feet. The differe 11.18 second-feet—represents the return seepage from the various canals.[b] In the of creeks tributary to Jordan River more measurements have been made, of which th Big Cottonwood and Mill valleys are typical. In Big Cottonwood Creek Valley Mr. Morgan selected for measurement two sections of the creek on which different conditions In the upper section, immediately below the mouth of the canyon, the bed of the s is composed of large loose bowlders resting on coarse gravel, and the land on either covered with comparatively scanty vegetation. In the lower section, below the h Green ditch, the bed of the creek is comparatively smooth, and the land on both sides gated and covered with abundant vegetation The loss in the first section, in a dista 2½ miles, was 7.36 second-feet, a percentage of 22 6, while in the second section, a miles long, the loss was only 0.30 second-feet, a percentage of 2.4.[c] In Mill Creek Mr. Morgan also made measurements in two sections where different conditions exis one section, 2 miles long, he found a loss of 22.7 per cent; in the other, three-quarte mile long, he found a loss of 3.6 per cent.[d]

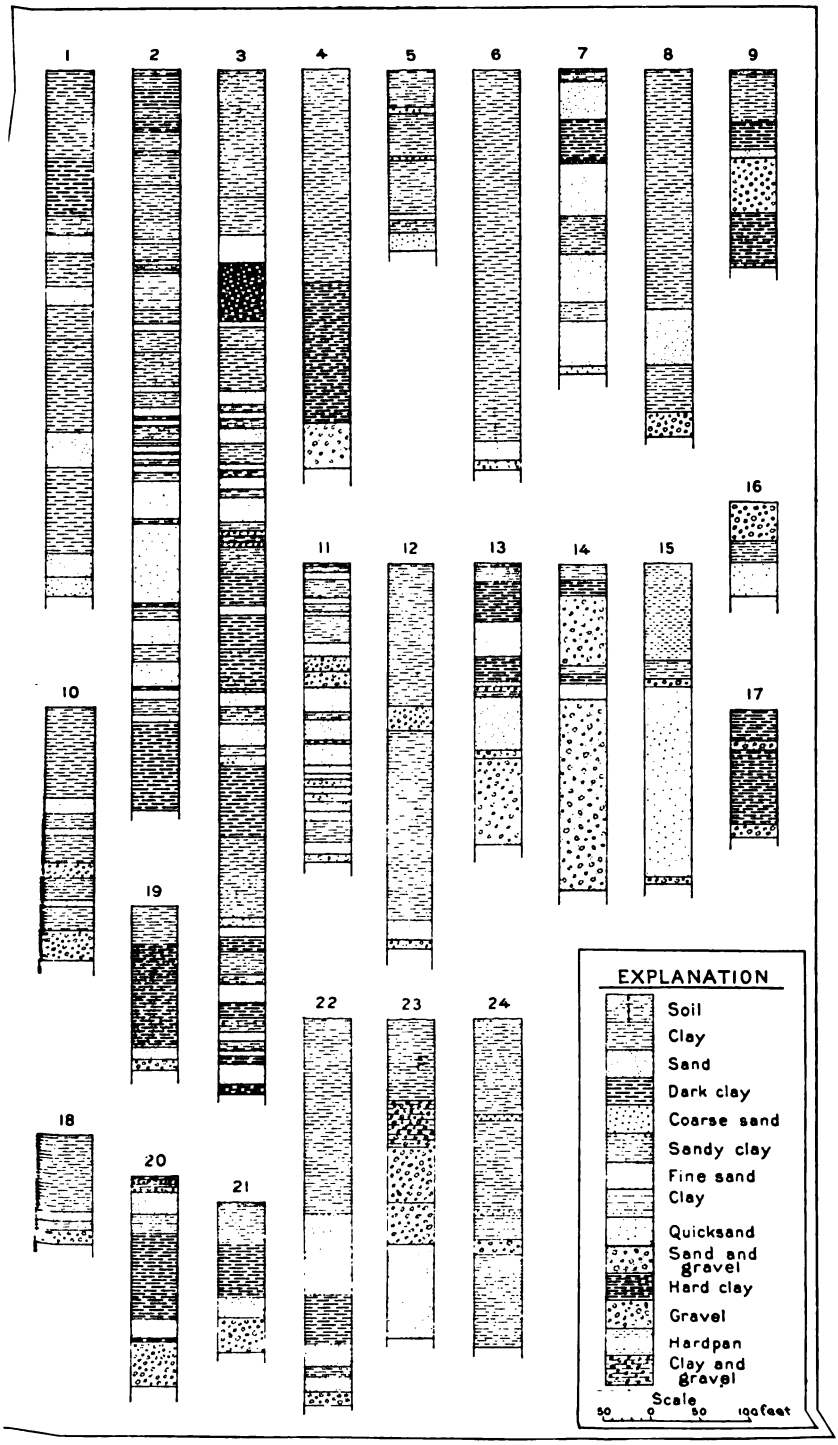
While seepage from the flow of the creeks and canals furnishes the chief supply of ground water to the valleys of Utah Lake and Jordan River, other sources are the und of the creeks at the mouths of the canyons, springs from bed rock, seepage at the b the mountains, and the small addition, already mentioned, derived from rainfall on the The underflow of the creeks at the mouths of the canyons is an important source, b amount thus contributed is unknown. The quantity equals the remainder after sub ing the sum of run-off and evaporation from the precipitation, of which factors on run-off is established, the precipitation being only approximately and the evaporatic at all known. The amount of the underflow can be directly determined, however, by a

[a] Bull. U. S. Dept. Agric. No. 124, Office Expt. Stations, 1903, p. 123.

[b] Ibid., p. 126.

[c] Morgan, E. R., Irrigation in Mountain water district, Salt Lake County, Utah: Bull. U. S. Agric. No. 133, Office Expt. Stations, 1903, pp. 60-61.

[d] Ibid., pp. 44-45.



WELL SECTIONS.

No. 1, Oregon Short Line well at Kaysville; No. 2, Southern Pacific Company's well at Strongs Point; Nos. 3-24, location shown on Pls VII and VIII.

measurements which should be made in estimating the feasibility of constructing subrface dams. The amount of water contributed to the valleys from bed-rock sources is so important. A remarkable series of thermal springs is associated with the great fault the western base of the Wasatch Mountains. These occur at intervals along the entire tent of the range, and other warm springs, which may also be connected with faults, are ated within the area under consideration. Association with faults suggests a deepated origin, which accounts for the high temperature of the water. The last source of the lley water supply to be mentioned is the comparatively small amount which is derived seepage from the base of the mountains from areas that are not drained by creeks.

DISTRIBUTION OF UNDERGROUND WATER.

From the outline of the geology given on pages 7–13 it will be seen that the valleys of Utah ake and Jordan River are occupied by a considerable but unknown thickness of gravel, nd, and clay derived from the disintegration of the adjacent mountains and deposited in e valley under alternating subaerial and lacustrine conditions. In general, the deposits e arranged in broad, sheet-like accumulations, the coarser-textured materials abounding djacent to the highlands and the finer débris preponderating farther out. The beds lie actically flat in the center of the basins, but are inclined slightly away from their source, e attitude of deposition being practically unaltered. Conditions of deposition, however, ere so varied that over large parts of the area considered the deposits are not widely iform. For instance, while clay was being laid down in one place sand was accumulating an adjacent area and at their border the two deposits were merged. Consequently the rangement of the beds is broadly lenticular, as is illustrated by the well records (Pl. V). o two records are exactly alike, and in most cases it is impossible to correlate deposits the different sections. Beds of clay are most widely distributed, but the more localized cumulations of sand and gravel, which are the most important reservoirs of underground ater, are irregularly distributed.

Underground water derived from the sources stated above occupies the spaces between e solid particles of the clay, sand, and gravel which constitute the valley filling. In neral, these deposits are saturated below the horizon which marks the surface of ground ater. The position of this surface varies, depending on the supply, on the amount used the intensity of evaporation, and on the character and slope of the sediments. The water seldom stagnant, but tends to flow with extreme slowness from a higher to a lower level, e chief factors in the movement being the number and size of the interstitial spaces in e deposits and the pressure gradient due to gravity. The highest velocity of ground ater ever determined is about 100 feet in twenty-four hours, but the ordinary velocity is uch less than this, common rates in sand being between 2 and 50 feet a day.

The fluctuation of the surface of ground water is considerable. Since the chief replenhment of the supply occurs when the creeks discharge the most and when the irrigation nals are in full operation, ground water occurs nearer the surface in summer than in inter. Conditions in different areas cause a varied annual range, but 10 feet is common nd 15 feet is not infrequent. In addition to the annual fluctuation a cumulative change in progress, the ground-water surface being gradually raised in the lower parts of the alley in consequence of irrigation and the custom of allowing artesian wells to flow unceasgly, leading to swampy conditions in the valley bottom. Details regarding these changes re given on subsequent pages.

Pl. VI illustrates the approximate average depths at which ground water occurs in the alleys of Utah Lake and Jordan River. The boundaries between the different areas uctuate and can not accurately be determined. A narrow belt contiguous to the base of he mountains is left blank on the map because of the varying and often unknown condiions that exist there, owing to seepage and the irregular distribution of water in the djacent bed rocks. In the absence of topographic maps the position of the water table n not be shown by contours.

Below the surface of ground water the saturated beds contain varying amounts, dependg on the character of the deposits. Coarse-textured gravel and sand, having a greater rosity than fine-textured clay, hold and transmit relatively more water. Beds of sand d gravel therefore constitute the chief underground reservoirs. Typical illustrations of distribution of sand and gravel are shown in Pl. V. In sinking wells in this region, beds

of sand and gravel, ranging from a few inches to a hundred feet or more and separated by varying thicknesses of clay, are encountered, water being commonly found in each porous deposit. Because of the prevailing inclination of the deposits away from the mountains, and of the presence of relatively impervious beds of clay above more porous sand and gravel, the contained water is under pressure. In the lowland areas this pressure is sufficient to cause the deep-seated water, when it is reached in a well, to rise and flow at the surface, and consequently artesian water is an important source of supply. Above the lowlands, where the surface elevation is too great for a flow to occur at the surface, the water rises in deep wells to a greater or less height according to the amount of pressure.

QUALITY OF UNDERGROUND WATER.

The accompanying analyses, gathered from a number of sources and reduced to common terms, illustrate the character of the water in the valleys of Utah Lake and Jordan River.

Analyses of water from streams and springs in valleys of Utah Lake and Jordan River.[a]

[Parts per million.]

No.	Source and date.	Ca.	Mg.	Na.	K.	Al_2O_3	Fe_2O_3	SiO_2	SO_4.	HCO_3.	CO_3.	Cl.	Total.
	CREEKS.												
1	City, Dec., 1882	55.3	18.9	2.6	24.3	2.0		19.9	7.3	.....	95.1	19.5	244.9
2	Red Butte, Dec., 1882	88.8	31.3	25.6	Trace	3.3		35.2	100.6	.....	108.8	22.9	416.5
3	Emigration, Dec., 1882	101.0	31.6	18.1	9.9	2.6		24.4	126.2	.....	102.7	28.6	445.1
4	Parleys, Dec., 1882	85.1	22.5	31.5	2.6	1.8		27.2	56.5	.....	122.1	19.7	369.0
5	Big Cottonwood, Oct., 1884	48.1	18.9	Trace.	8.6	1.6		12.6	42.1	.....	63.6	7.9	203.4
6	Little Cottonwood, Oct., 1884	17.5	8.2	5.9	1.7	1.3		39.9	12.3	.....	32.2	2.8	121.8
7	Dry Cottonwood	17.0	27.0	15.0	14.0	.....		.....	34.0	121.0	.....	14.0	242.0
8	American Fork	45.0	24.0	4.0	10.0	.....		.....	42.0	145.0	.....	Trace.	270.0
9	Payson	12.0	17.0	22.0	3.0	.....		.....	32.0	121.0	14.0	.....	221.0
10	Santaquin	12.0	31.0	31.0	5.0	.....		.....	33.0	212.0	14.0	.....	338.0
11	Currant	47.0	54.0	89.0	44.0	.....		.....	115.0	181.0	15.0	211.0	756.0
12	Warm	114.0	48.0	381.0	92.0	.....		.....	114.0	333.0	28.0	703.0	1,813.0
	RIVERS.												
13	Provo	51.0	29.0	28.0	22.0	.....		.....	44.0	205.0	.....	28.0	397.0
14	Spanish Fork	68.0	36.0	46.0	17.0	.....		.....	64.0	277.0	.....	28.0	536.0
	Jordan:												
15	Utah Lake (outlet), 1899	67.6	13.8	233.7	2.0	.....		.....	236.7	.....	23.7	316.5	894.0
16	Salt Lake City (near), 1899	111.8	13.7	251.1	.....	.....		.....	334.5	.....	Trace	378.9	1,090.0
	WARM SPRINGS.												
17	Salt Lake City, Oct., 1881	535.2	138.4	3,039.0	178.0	0.7		21.3	787.5	.....	442.9	4,968.0	10,284.0
18	Beck's (hot)	694.3	109.5	3,754.9	196.9	9.0	.....	31.5	840.5	.....	204.5	6,743.8	12,584.9
19	Sandy (8 mi. s.), Mar. 1882	141.5	27.7	405.0	55.0	5.1		50.5	53.8	.....	272.7	635.6	1,658.0
	UTAH LAKE.												
20	1883	55.8	18.6	17.7	2.0	.....		10.0	130.6	.....	60.9	12.4	308.0
21	1904	67.0	86.0	230.0	22.0	.....		28.0	378.0	194.0	11.0	337.0	1,353.0

[a] AUTHORITIES.—Nos. 1-5, 17, 19, Kingsbury, J. T. Nos. 6-14, Soil survey of the Provo area, Utah: Bureau of Soils U. S. Dept. Agric., 1904, p. 22. Nos. 15, 20, and 21, Cameron, F. K. Water of Utah Lake: Jour. Am. Chem. Soc., vol. 37, No. 2, 1905. No. 16, ibid., Rept. No. 64 U. S. Dept. Agric. No. 18, Riggs, R. B., Bull. U. S. Geol. Survey No. 42, 1887, p. 148. No. 20, Clarke, F. W. No. 21, Brown, R. E.

'he average of analyses of 12 streams [a] coming from the Wasatch Mountains shows a ıl solid content of 319 parts per million, ranging from 122 to 536, the varying character he water being due to differences in the rocks of the respective watersheds. Examina- ı of these analyses shows that calcium is usually the most abundant base, with magne- n a poor second, while sodium and potassium generally are much less plentiful and y in relative amounts. Among the acid radicals, carbonic commonly preponderates, ng often several times more abundant than the others; sulphuric ranks next, and in a ' streams is important, while chlorine is generally of minor occurrence. Little Cotton- od Creek ranks first, having only 121.8 parts per million of dissolved solids. It flows most of its course through granitic rock and therefore contains but little calcium car- ıate. The total solids in Big Cottonwood Creek water are also low and relatively little ıe is present because a large part of the drainage is over silicious rocks. The great ındance of limestone on most of the watersheds accounts for the abundance of calcium bonate. Red Butte, Emigration, and Parleys creeks make a relatively poor showing, ı sulphates being especially abundant, because these streams flow over Permo-Carbon- ous and Mesozoic rocks containing more or less gypsiferous matter. Provo River and anish Fork drain large areas occupied by a variety of rocks, among which limestone is ıminent, and the analyses show rather high amounts of total solids, the carbonates ng particularly abundant. Currant and Warm creeks are exceptional. The unusual ount of sodium chloride present in Currant Creek is derived from salt deposits above phi. Warm Creek rises in the springs west of Goshen, and the character of its water, ɜ that of similar springs in this area, is due to unusual conditions.

The few analyses of the thermal springs in the area under consideration show the presence abundant dissolved salts, of which the chlorides are the most plentiful, though consid- ble quantities of sulphates and carbonates are also present. Sodium is several times re abundant than any other base, calcium ranks second, and magnesium and potassium present in small amounts. Some of the hot springs contain considerable hydrogen phide. Most, if not all, of these springs are associated with faults and have a deep- ted origin, to which their temperature and composition are due. The mineral matter leached from the deposits through which the waters pass, much of the salt content ng probably derived from old lake beds.

Analyses of water from flowing wells are similar to those of surface streams. Different lls give different results, the quality of the water varying with the source and the nature the deposits passed through underground. Analyses from the "Murray" and "Ger- ınia" wells show an unusually small content of total solids, while those from the wells the Utah Sugar Company at Lehi and near Provo show amounts above the average. the area contiguous to Great Salt Lake the well water contains considerable salt, but analyses were obtained. In general the water from flowing wells is of admirable ality and often forms a marked contrast to the supply from shallow wells.

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[a] Omitting Currant and Warm creeks, which are exceptional.

Analyses of water from wells, etc., in valleys of Utah Lake and Jordan River.[a]

[Parts per million.]

No.	Source and date.	Ca.	Mg.	Na.	Al_2O_3. Fe_2O_3.	SiO_2.	SO_4.	CO_3.	Cl.	Na_2CO_3 K_2CO_3.	Na_2SO_4 K_2SO_4.	Na Cl KCl.	Total solids.
22	Mill Pond at Lehi, July, 1895.	82	54	.....	16.0	11	[d] 196	[b] 135	.....	124	0	152	80
23	Artesian well, Murray Plant, Am. Smelting and Refining Co.	23	6.6	.....	1.4	14	[d] 14	42	.....	.....	Tr.	11	11
24	Artesian well, Germania Plant, Am. Smelting and Refining Co.	24	8.7	.....	1	9.7	[d] 12	64	.....	.....	6.8	28	10
25	U. S. Mining Co. well, Bingham Junction, Aug., 1902.	37	13	.....	2.4	14	[d] 50	56	.....	.....	27	87	29
26	U. S. Mining Co. well, West Jordan, Aug., 1902.	11	5	.....	1	13	.....	[c] 30	68	.....	44	58	22
27	Wm. Cooper's well, Bingham Junction	34	11	.....	1.2	16	[d] 16	66	.....	.....	45	87	29
28	Beet-cutting station, Utah Sugar Co. well, near Provo, Jan., 1899.	74	29	.....	5	58	.....	[c] 180	89	.....	116	103	63
29	Artesian well, Utah Sugar Co., Lehi, Jan., 1899.	62	38	.....	Tr.	12	154	[c] 91	21	.....	.....	287	60
30	R. G. W. Rwy. well, Springville, May, 1901.	157	19	14	4	18	41	120	21	.....	.....	.....	.....
31	R. G. W. Rwy. well, Goshen, May, 1901.	85	32	104	90	80	47	127	160	.....	.....	.....	.....

[a] AUTHORITIES.—Nos. 22, 28, and 29, Dearborn laboratories. Nos. 25 and 26, Converse, W. A. No. 27, J. H. Parsons Chemical Co. Nos. 30 and 31, De Bernard, J. H.
[b] From $MgCO_3$.
[c] From $CaCO_3$ and $MgCO_3$.
[d] From $CaSO_4$.

No analyses of ground water obtained from shallow wells are available, but the general character of such water is known. In the upland areas above the canals the water from shallow wells is much like that commonly obtained throughout the region in deeper ones; it contains a moderate amount of dissolved salts, largely calcium carbonate, and is usually of good quality. But in the lowlands the surface water is quite different, generally containing considerable dissolved salts, among which alkalies are abundant. Where ground water lies within the scope of capillary attraction from the surface, evaporation causes the mineral matter which is held in solution to accumulate, and in this manner the soil becomes tainted with alkali. Consequently the water from surface wells in the lowlands is characteristically rich in dissolved salts.

Abnormal conditions prevail locally in the vicinity of the smelters in Jordan Valley south of Salt Lake City. Smelter smoke has lately become a nuisance to farmers by injuring crops and animals in the path of prevailing winds. Sulphur dioxide is the most abundant deleterious substance contained in the smoke, and to a minor extent locally finds its way into the water supply. Occasionally also ground water may become poisoned from accumulations of flue dust containing copper and arsenic.[a]

Natural gas occurs in a number of water wells in the area under consideration. Well drivers report the common presence of vegetable matter, chiefly fragments of wood, at different depths in many localities. This was entombed in the old lake deposits, and its decomposition may account for the origin of the gas. Though gas occurs in numerous wells it has been found in quantity in only a few localities, the greatest development occurring near the shore of Great Salt Lake, about 12 miles north of Salt Lake City.[b] Here several wells were drilled averaging about 500 feet in depth; and from September, 189[illegible]

[a] Widtsoe, J. A., Relation of smelter smoke to Utah agriculture: Bull. Agricultural College of Utah, No. 88, 1903.

[b] *Richardson, G. B.*, Natural gas near Salt Lake City: Bull. U. S. Geol. Survey No. 260, 1905, p. 4[illegible]

March, 1897, Salt Lake City was supplied with natural gas from this source, the total d being approximately 150,000,000 cubic feet. But the supply finally became insuffi- it and the field was abandoned. Gas continues to be found in various parts of the valley possibly other fields similar to that north of Salt Lake City may yet be found; but re is little reason for expecting much better results than already obtained and it is ossible to predict the localities where such supplies may be found.

he water of Utah Lake represents the varied sources of its supply; part is derived ctly from surface streams, another part from seepage, still another portion from springs, the whole is concentrated by evaporation. The analysis by the Bureau of Soils on e 30 shows the present condition of the water. Sodium predominates, magnesium and ium are subordinate, and the corresponding salts are principally sulphates and chlorides. parison with an analysis of Utah Lake by F. W. Clarke twenty-one years earlier affords resting data.[a] The total solids have increased from 308 to 1,353 parts per million, the character of the water has changed from a preponderating sulphate solution to containing large amounts of chlorides; the sodium has increased remarkably and gnesium is now in excess of calcium. These changes appear to be mainly due to man's pancy of the region. The streams have been diverted for irrigation and an increasing ply has reached the lake as seepage after passing through the alkaline soils of the low- ds. Evaporation in the shallow lake also has tended to concentrate its waters.

he composition of the water of Great Salt Lake has been the subject of much investi- ion, and a list of the more important analyses is given on page 34. The lake receives drainage of an enormous area, but by far the greater part of its supply is derived from Wasatch Mountains, from Bear, Weber, and Jordan rivers. The mineral content of at Salt Lake is the result of the concentration of a vast body of water during a long iod of time, in which Lake Bonneville has given place by evaporation to the present e. Great Salt Lake is shallow, and the seasonal and annual fluctuations in its level se considerable differences in volume, with consequent changes in composition of the er. These changes are indicated by the increase of salinity from 13 per cent in 1873 about 24 per cent in 1892.

n August, 1892, the water of Great Salt Lake contained 238 parts per thousand of al solids, consisting of predominating sodium and smaller amounts of magnesium, potas- n, and calcium, in the order named, the corresponding salts being chlorides and sul- tes. The water of the lake is thus a concentrated brine, and in the winter months point of saturation for sodium sulphate is actually reached and crystals of mirabilite[b] deposited. The critical point for calcium carbonate is passed, so that, in spite of its ndance in the waters that supply the lake, none has been found in it. Apparently ium carbonate is precipitated soon after entering the dense body of water.

[a] Cameron, F. K., Jour. Am. Chem. Soc. vol. 37, 1905, p. 113.

[b] Talmage, J. E., "Great Salt Lake, Present and Past," 1900, p. 64.

Analyses of water of Great Salt Lake. [a]

[Parts per thousand.]

Analyst and date.	Ca.	Mg.	Na.	K.	SO_4.	Cl.	B_2O_3.	P_2O_5.	Total.	Specific gravity
Gale, L. D., 1850	Trace.	0.6	85.3	.....	12.4	124.5	.....	.....	222.8	1.170
Allen, O. D., summer, 1869	0.2	3.8	49.6	2.4	9.9	84.0	Trace.	Trace.	149.9	1.111
Bassett, H., Aug., 1873	.6	3.0	38.3	9.9	8.8	73.6	.....	.....	134.2	1.102
Talmage, J. E.:										
Dec., 1885	.4	2.9	58.2	1.9	13.1	90.7	.....	.....	167.2	1.122
Aug., 1889	.8	5.1	65.3	2.1	11.7	110.5	.....	.....	195.5	1.157
Waller, E., Aug., 1892	2.424	2.844	75.825	3.925	14.964	128.278	Trace.	.....	[b]238.12	1.186

[a] Waller, E., Water of Great Salt Lake: School of Mines Quart., vol. 14, 1893, p. 59.
[b] By evaporation, duplicate test gave 237.93.

Too little care is given to the sanitary character of the waters in the valleys of Utah Lake and Jordan River. The mountain streams are a source of excellent purity, yet they are liable to contamination. General supervision of the watersheds of the creeks that supply Salt Lake City is maintained by the municipality, especially on City Creek, but elsewhere few precautions are taken to safeguard the supply. Commonly the character of water obtained from the deep wells is of good quality, as is also that of surface wells in the thinly settled uplands adjacent to the base of the mountains. But surface water generally, especially in the thickly settled lowlands, where, moreover, the mineral content is high, is undesirable for domestic use because of its liability to contamination.

Salt Lake and Provo are the only cities in the area that have sewer systems. The Provo sewer discharges through an open ditch into Utah Lake, and thereby pollutes that body of water. Salt Lake City's sewage is well disposed of on a "sewer farm" below Hot Springs Lake, and the surplus enters Jordan River near its mouth. Elsewhere no systematic sanitary precautions are taken, and locally conditions are bad, with consequent frequent typhoid fever epidemics.

It can not be too strongly impressed upon inhabitants of country districts that the welfare of the community is intimately concerned with preserving the water supply uncontaminated, and in this connection it may be of service to reproduce a section from the ninth annual report of the Massachusetts State board of health: [a]

There are a few points to be borne in mind with reference to water supply, drainage of houses, and sewerage, which have been suggested by the examination of the board in this State, and may properly be summarized here.

1. The privy system, so common throughout the State, by which filth is stored up to pollute the air, soil, and water near dwellings, should in all cases be abolished.

2. Cesspools, unless extraordinary precautions be taken as to ventilation and prevention of pollution of soil and air, are little better, and should be given up for something less objectionable as soon as practicable.

3. Wells can not be depended on for supplies of wholesome water unless they are thoroughly guarded from sources of surface and subsoil pollution. Some of the foulest well water examined by the board has been clear, sparkling, and of not unpleasant taste.

4. Where wells have already been polluted and it is not practicable to dig new deep wells remote from sources of contamination or to introduce pure public water supplies, the storage of rain water, properly filtered, is a satisfactory method of procedure.

5. In small towns where public water supplies have not been introduced, and, indeed, wherever water-closets are not used, some method of frequent removal and disinfection with earth or ashes should be adopted in place of privies, by which it should be impossible for the filth to soak into the soil or escape into the air. Cemented vaults are not always to be depended upon, as their walls crack from frost or through settling of the ground, and they thus sometimes become sources of pollution of wells, besides contaminating the air. Nor is the fact of a privy being on a downward slope from the well a sufficient safeguard, for even then the direction of the subsoil drainage may be toward the well.

[a] *Rafter*, G. W., and Baker, M. N., Sewage Disposal in the United States, 1894, p. 45.

6. Earth closets, with proper care, may be satisfactorily adopted, but the earth, after having been once used, should be placed upon the land, not stored within doors and dried to be again used, for in the process of drying there are emanations from it which are, perhaps, not less dangerous from the fact of their being imperceptible by the unaided senses or through chemical examination. With earth closets a plan similar to that in use at the Pittsfield Hospital [a] may well be used for the chamber slops, and the kitchen waste may be utilized (with the chamber slops too, if desired) in the manner used by Mr. Field and Colonel Waring. * * * Less intricate methods are used in scattered dwellings, but with the effect of having the slop water absorbed by the ground and taken up by vegetation so far from the house as not to involve a nuisance or danger to health.

7. Where water supplies, water-closets, etc., are introduced, sewers should follow immediately in most kinds of soil. Cesspools should not be used, unless with extraordinary precautions; but with a few hundred feet square of lawn the irrigation system by agricultural drain pipes is to be recommended, whereby the filth is at once taken up by the roots of grass. In all cases, of course, with or without cesspools, there should be thorough ventilation of the system of house drainage, with disconnection from the main outlet drain by means of either a ventilating pipe or rain-water spout between the sewer trap and the house, and whose openings at the top should be only at points remote from windows and chimney tops.

On the whole, a thoroughly satisfactory arrangement of this kind, if properly looked after, is in many respects to be preferred to connecting with public sewers.

RECOVERY OF UNDERGROUND WATER.

A crude estimate of the amount of underground water in the valleys of Utah Lake and Jordan River might be made, based on an assumed thickness and porosity of the unconsolidated sediments, and the result would be many cubic miles, yet the figures would be valueless. The important fact is the amount of available water that can be recovered economically; but, unfortunately, this too, because of lack of detailed knowledge concerning the distribution and thickness of the beds of sand and gravel which constitute the reservoirs, can not be determined. Though definite figures are not available, the general fact is well known that the lowlands are amply supplied with underground water within easy reach of the surface and that on the highlands the underground supply is relatively small.

Underground water becomes available for use both naturally and artificially. It reaches the surface again naturally in springs and by seepage into drainageways, and is commonly recovered artificially by means of wells, though occasionally tunnels and subsurface dams prove efficacious. Wells are the main recourse in the area under consideration, and they can be conveniently grouped into two classes, flowing and nonflowing.

The areas in which flowing wells are obtained in the valleys of Utah Lake and Jordan River are shown on Pls. VIII and IX, and the list of wells, together with the descriptions of the different localities, gives detailed information concerning the occurrence of artesian water.

The date when the first flowing well was put down has not been ascertained, but it appears to have been about 1878. Since then many have been sunk, and the limits of the areas in which flows can be obtained have been determined with fair accuracy by experiment. The map shows that flowing wells exist only in the lower portions of the valley, the area of flows corresponding closely with that in which ground water lies within 10 feet of the surface. Higher up on the benches the elevation is too great to obtain flows.

Locally, flowing wells may be obtained at a depth of less than 50 feet, but generally they range between 100 and 400 feet, while the few that have been sunk to 1,000 feet and more encountered water under pressure in the successive beds of sand and gravel. As many as 25 distinct water horizons from which flows at the surface were obtained are reported in the Rudy well, sec. 6, T. 1 N., R. 1 W. The wells are usually 2 inches in diameter, though occasionally the shallower ones are only 1 inch, while the deeper ones are 4 and 6 inches. In yield the wells vary considerably, according to location, depth, and size of pipe. The greatest flow measured was that in the Harry Gammon well, sec. 7, T. 6 S., R. 2 E., which supplies about 266 gallons a minute from a 3-inch pipe. A number of wells flow less than 1 gallon a minute, though a common yield is between 10 and 60 gallons. The pressure is comparatively low, the highest measurements obtained being only 15½ pounds per square

[a] Cottage *Hospitals: Ninth* Ann. Rept. Mass. State Board of Health, pp. 83-95.

inch, and generally the greatest pressures are little more than sufficient to raise the wa into railroad tanks.

Temperature measurements of the water from flowing wells afford some data bearing the downward increment of heat in the unconsolidated valley deposits, but there ar number of disturbing factors. Adjacent to the mountains the waters are unusually c the presence of hot springs tends to disturb conditions, and the depths from which the wa flow are often not known. The common rate of downward increase in temperature app to be slightly less than 1° F. in 50 feet, but the facts obtained do not warrant a cl statement. It may be of local interest, however, to observe that in general the temp ture of the water increases with the depth of the wells at approximately that rate.

Few measurements have been made, but it is common experience that the yield of m flowing wells in the area under consideration has decreased. The most comprehen measurements are those made of the wells owned by Salt Lake City near Liberty P (p. 44). Comparing the discharge of 12 of these wells in August, 1890, with the yield of same wells in September, 1902, it appears that in the interval of twelve years the flo one had increased, but that those of the others had materially decreased. Such decre however, may be due largely to clogging of the pipes, for the total yield of the Liberty P area has been maintained with little decrease by sinking new wells.

Decrease in yield is conspicuously apparent in Lehi and Spanish Fork, where flo wells formerly could be obtained much more generally than now, and is notable elsewl throughout the valley, especially adjacent to the boundary of the flowing area. Decre in flow of individual wells is so metimes due to clogging up with sand and clay, and o can be remedied by cleaning or by the use of casing. But the general decrease is to explained chiefly by the large increase in the number of wells which draw on the gen supply. It is also to be remembered that for the past few years the annual precipita has been considerably below the mean.

The artesian wells are used for stock, irrigation, and domestic purposes. The amo used for stock is comparatively small, and, save for watering small gardens, artesian w as yet is not extensively used for irrigation, except locally. Probably over a thousand a are thus irrigated in Utah Lake Valley, the principal areas being below Lehi and Pay The artesian supply is much used for domestic purposes, and in general furnishes an a rable quality of water, containing much less dissolved salts and being much purer shallow ground water.

An attempt was made to estimate the total number of flowing wells in the area stu but the result is to be taken only as a rough approximation. There are about 5,000 ing wells in the valleys of Utah Lake and Jordan River, and possibly somewhat more half of these occur in the southern valley. Assuming an average of 15 gallons a minu total yield of about 150 second-feet is thus indicated.

Outside of the area in which flowing wells are obtained underground water is reco either from shallow dug wells that tap the upper surface of underground water or driven wells in which the water comes from a relatively deep horizon and is under pre which causes it to rise toward the surface. To save the expense of "driving," shallow are often dug within the area in which flowing wells can be obtained. Occupying the c of the valley and extending approximately to the limit at which flowing wells ca obtained, ground water lies within 10 feet of the surface, and locally, as has been menti swampy conditions exist. As the base of the mountains is approached the depth to gr water increases and is over 50 feet on much of the upland where, over large areas, th tance to water is unknown.

Water is recovered from these wells generally by buckets and hand pumps. Comparat few windmills are in operation. An average wind velocity of not less than 6 miles an h is stated to be required to drive a windmill; and since the mean wind velocity at Salt

[a] Wilson, H. M., Pumping for irrigation: Water-Sup. and Irr. Paper No. 1, U. S. Geol. Su *1896, p. 27.*

City from June to September, inclusive, is 6.5 miles an hour and for the entire year averages only 5.9 miles, the natural conditions are not very favorable for this form of power. Steam pumps are used only to a limited extent. The Bingham Consolidated Company has three 3-inch wells 250 to 300 feet deep in which the water rises to within about 70 feet of the surface; 125 gallons per minute are reported to be supplied by each, the water being raised by compressed air. Another instance of successful pumping is at the brickyard in sec. 29, T. 1 S., R. 1 E., where 40 gallons a minute are reported to be obtained from a well 30 feet deep. Gasoline for pumping has not been much used. Electric power can be cheaply developed in the canyons and affords a valuable asset. In the valleys of Utah Lake and Jordan River pumping on a large scale has not yet been resorted to. There is, however, a considerable quantity of water within easy reach of the surface which probably will not much longer remain unused.

Underground water is recovered in exceptional circumstances by means of subsurface dams, or similar contrivances, which impound the underground supply. In unconsolidated materials, in order that this may be successfully accomplished, certain conditions are necessary. Practically impervious bottom must exist within easy reach of the surface to prevent excessive lowering of the ground-water level, and competent side walls, not too far apart, should be present to intercept lateral escape. The presence of the necessary conditions can be determined only by prospecting, and the practicability of such structures is an independent question, but because of the value of water in the area under consideration their feasibility should be investigated. Possible locations of subsurface dams are suggested by rock walls at the mouths of the narrow canyons, where borings in search of suitable bottom should be made. Tests of the amount and porosity of the valley filling at and above the mouths of the canyons, together with measurements of the velocity of the underflow, would indicate the quantity of available underground water. On Emigration Creek, for instance, the comparatively low run-off, suggesting an unusual amount of underdrainage, and the quantity of water obtained from the inefficient city trench invite further testing of the possibilities. Below the mouths of the canyons in the several creek valleys favorable conditions also may be discovered by the drill to warrant the construction of infiltration galleries.

In the section devoted to geology it is stated that the rocks of this region are more or less disturbed and broken, and an important part of the precipitation on the mountains finds its way into the bed rock. The water occurs in the small interstices or pores which are present in all rocks, in larger spaces such as fissures or solution channels, and along joints, bedding planes, and igneous contacts. As would be expected, less water is found in the Oquirrh Mountains than in the Wasatch. Bingham is a dry camp, though more or less water is encountered in the workings, while the mines of Park City are wet. The Ontario tunnel, which drains most of the large mines of the latter district, is stated by J. M. Boutwell to discharge from 6,000 to 9,000 gallons a minute. Considerable water is being recovered by tunnels driven into bed rock along the base of the mountains. In some instances the site of the tunnel marks the presence of a former spring, as, for instance, Wadleys, near Pleasant Grove, and those in Butterfield Canyon. But in one, the Dalton and Lark tunnel, east of Bingham, water in quantity was not encountered until several thousand feet of rock were penetrated.

Another method of recovering water from bed rock is suggested by the structure of the mountains southeast of Salt Lake City. It will be recalled from the outline of the geology that a great syncline, modified by local undulations, is there developed, whose axis extends along the valley of Emigration Creek. The general structure is favorable for the occurrence of artesian water, but there are unfavorable complications. The rocks are chiefly compact limestones, the general disturbed and fissured conditions tend to relieve the pressure on the interstitial water, and the Wasatch fault has cut across the strata. Nevertheless, it is possible that locally the red sandstones contain water under pressure, but because of the limited intake area a large supply is not to be expected.

SUGGESTIONS.

It is evident that in general a high degree of efficiency in the use of the water resources of the valleys of Utah Lake and Jordan River is not maintained. Conditions can be greatly benefited by preventing waste whenever possible. Most prominent in this connection is the conservation of storm waters. Besides the construction of large impounding reservoirs small ones can profitably be built at many localities within the mountains. Also to a certain extent storm waters can be utilized by diverting them on the uplands and permitting them to spread over a larger area instead of allowing the run-off to escape rapidly in the natural channels. The effect would be an appreciable increase of the downstream seepage and of the replenishment of the underground store. Moreover, storm discharge may be lessened by planting trees and by protecting the watershed from fire, lumbering, and grazing, thereby promoting retention of the water by absorption and the increase of seepage run-off long after the storms are over. Another important loss of water occurs because of faulty methods of transportation for use in irrigation. As the need of economy increases more efficient conduits will replace crudely constructed ditches. Water thus saved, however, proportionally diminishes the replenishment of the underground store. Loss also occurs by allowing artesian wells to flow when the water is not needed. Either the wells should be capped or the flow at least be partly checked when water is not used, or it should be collected in reservoirs.

The abundance of water in the lowlands and a dearth of it in the uplands, where the soil is generally fertile, free from alkali, and well adapted to the growth of fruit, suggest that a more efficient application of the available water supply should be practiced. Because of the scarcity of the underground supply on the uplands and the possibility of distributing creek water there by high-level canals, and since there is not enough water in the creeks to directly serve both the uplands and lowlands, it would appear that steps should be taken to increase the upland supply from the creeks and to use wells, either flowing or pumped, in developing the lowlands. The popularity of pumping plants in irrigation elsewhere, the proximity of underground water to the surface in the lowlands, and the availability of electric power that can be developed in the adjacent canyons are facts favorable to the proposed change. Moreover, seepage from the greater use of creek water on the uplands will increase the available underground supply in the lowlands. The upland water supply may also be increased by the development of springs, by tunneling into the mountains, and possibly by the construction of subsurface dams and infiltration galleries at favorable localities.

More attention should be given to developing and preserving a pure water supply for domestic purposes. Surface streams should be protected from pollution, and care should be taken to reduce to a minimum the contamination of water in wells by using modern methods in the disposal of household refuse. The common location of the towns, near the base of the mountains, where sufficient amounts of pure water are generally available either from creeks or springs renders the problem of public water supply relatively simple; yet it is a remarkable fact that only a few towns utilize their opportunities.

OCCURRENCE OF UNDERGROUND WATER.

WEST OF JORDAN RIVER.

DIVISIONS OF AREA.

The area west of Jordan River within the region covered by this report is naturally divided into two parts. One is the lowland which extends from Great Salt Lake eastward to Jordan River and thence continues in a narrow belt southward, adjacent to the river; the other is the upland which, from the southern and western border of the lowland, extends with increasing elevation to the base of the Oquirrh Mountains. No sharp line of division can be drawn between these areas, for they grade into each other, yet on the whole they are distinct. The distribution of underground water in the two areas also is distinct, a convenient line of separation being that which marks the boundary between flowing and

nflowing wells. As shown by Pl. VII, this line lies close to the Jordan in the southern rt of its course, but across the river from Murray takes a westward turn, and, following e base of the upland, extends to Great Salt Lake at the northern base of the Oquirrh ountains. This line also roughly marks the boundary between shallow and deep ground ater. In the lowland area ground water is abundant and generally lies within 10 feet of e surface, while on the upland water is generally scarce and is found only at a depth of er 50 feet.

UPLAND AREA WEST OF JORDAN RIVER.

In general the upland has the aspect of a rolling plain which gradually rises to the base the mountains, but in detail the plain is varied by the presence of benches and escarpents, relics of Lake Bonneville and of a few drainage ways that have incised channels ross the plain. Locally, especially at the northern end of the Oquirrh Mountains and at Narrows, where Jordan River flows through the Traverse Mountains, the shore lines Lake Bonneville are unusually well marked. Different stages of the lake's history are orded by a series of distinct benches, which descend one below another from the Bonnele level; at Jordan Narrows, for instance, no less than ten periods of pause in the lake el are thus recorded. Shore phenomena in general, however, are less prominently rked on the western margin of Jordan Valley than on the eastern, adjacent to the atch Mountains.

Bingham Creek is the only perennially flowing stream which runs for any considerable ent across the plain, though Butterfield Creek flows for a short distance after it emerges m the mountains southwest of the town of Herriman. This area is also traversed by a mber of arroyos which contain water only for a few days after storms and during the e of rapidly melting snow. The Utah and Salt Lake and the South Jordan canals, rying water from the upper part of Jordan River, extend along the eastern border of upland and supply irrigation water to a narrow belt. Above the upper canal the area lesert and practically uninhabited, except for the town of Herriman and a few scattering ches which obtain local supplies of water. The Utah Lake project of the Reclamation vice plans to make available for irrigation a belt from 2 to 4 miles wide west of the Utah l Salt Lake canal, but a large part of this upland area west of Jordan River has too great elevation to be cheaply irrigated from Jordan River. Some amelioration of the present l conditions may be effected by constructing reservoirs at the base of the mountains, the collecting area is small and no very extensive additions to the water supply are ly to be derived from this source. More or less dry farming is already practiced here. land is fertile, is practically free from alkali, and because of its location would be very uable if an adequate supply of water could be obtained. Unfortunately, so far as wn, underground water conditions afford little prospect of a large supply from that rce, though valuable quantities can locally be recovered.

This upland area is largely underlain by gravel and sand, and along the base of the mountains coarse gravel predominates. The material was derived from the disintegration of adjacent highlands and mostly deposited offshore in the ancient lake. The constitus have been worked over and sorted during the different stages of the lake's history, h by wave action and by subaerial influences, so that the resulting material is heteroeous both as to its composition and arrangement.

Drills have recorded only to a very limited extent the nature of the deposits that underlie surface. Judging from the records and from conditions elsewhere, it is probable that rock lies not far from the surface contiguous to the base of the mountains, and that at istance from the highland bed rock lies at a considerable, though unknown, depth. rer the mountains the unconsolidated valley filling is doubtless of coarser texture n farther away, and it is likely that the materials are arranged lenticularly rather than continuous beds. That portion of the slight precipitation on the low, small watershed he Oquirrh and Traverse mountains that is not evaporated or does not join the permanent off is absorbed by the porous deposits. Under the influence of gravity the water

Record of Rio Grande Western Railway Company's well at Salt Lake City.

	Thickness in feet.	Depth in feet.
Thin strata of clay and sand	130	1–130
Clay and hardpan	40	130–170
Red sand	30	170–200
Clay and hardpan	60	200–260
Gray sand	5	260–265
Clay and sand	44	265–309
Sand	8	309–317
Clay	20	317–337
Sand	13	337–350
Hard clay	6	350–356
Sand	8	356–364
Clay	10	364–374
Sand	18	374–392
Clay	20	392–412
Sand	4	412–416
Clay	10	416–426
Blue sand	12	426–438
Clay	5	438–443
Blue sand	30	443–473
Hard clay	10	473–483
Sand and gravel	1	483–484
Clay	12	484–496
Gravel	4	496–500
Gray sandy clay	28	500–528
Tough blue clay	30	528–558
Hardpan	3	558–561
Sand	8	561–569
Soft blue clay	40	569–609
Sandy blue clay	40	609–649
Hardpan	2	649–651
Sand	16	651–667
Sandy gray clay	18	667–685
Red sand	36	685–721
Gravel	10	721–731
Blue clay	76	731–807
Clay and sand, alternating every 12 or 18 inches	84	807–891
Hardpan	8	891–899
Sand and gravel	11	899–910
Blue clay	16	910–926
Gray clay	24	926–950
Sandy gray clay	13	950–963
Quick sand	15	963–978
Blue clay	21	978–999
Sandy blue clay	11	999–1,010
Quicksand	10	1,010–1,020
Gray clay	11	1,020–1,031
Fine blue sand	3	1,031–1,034
Tough blue clay	12	1,034–1,046
Hardpan	2	1,046–1,048
Fine sand	21	1,048–1,069
Hard blue clay	4	1,069–1,073

Although the general composition of the old lake deposits is known, not enough information has been accumulated to enable very definite statements to be made concerning the detailed distribution of the sediments. A comparison of available well records shows that the alternating beds of sand, clay, and gravel, generally, can not be recognized as being equivalent in the several wells, and from the present evidence it appears that while there are great thicknesses of both sand and clay, which must have a more considerable lateral extent than the beds nearer the mountains, the lake deposits are lenticularly arranged. Since no correlation has been established, the structure of the lake deposits is not known. Apparently they are approximately horizontal, but with a slight inclination toward the lake from the highlands. This is indicated by the pressure obtained in artesian wells and is proved in a few instances by well records.

In the broad lowland west of Jordan River there is an abundance of water. Throughout practially all of this area ground water lies within 10 feet of the surface, and water is contained in the underlying deposits down to an unknown but considerable depth. Apparently flowing wells can be obtained anywhere within this area. Although the water is so generally distributed, it is profitably recovered only from the more porous, coarser textured deposits of sand and gravel, which constitute natural reservoirs and in which the water moves more readily. Accordingly, water is found at several horizons in the course of sinking a deep well. In the Rudy well, for instance, 1,002 feet deep, situated in sec. 5, T. 1 N., R. 1 W., 25 water horizons from which surface flows were obtained are reported. A record of this well is not available, but "good strong" flows besides minor ones were recorded, respectively, at 400, 508, 685, 753, and 881 feet.

Though water is so abundant, this lowland region is thinly populated, the chief drawback to its settlement being the presence of much alkali in the soil over a considerable part of

he area. The Bureau of Soils of the United States Department of Agriculture, in coopera-
ion with the Utah Experiment Station, is at present engaged in a demonstration of the
easibility of reclaiming this land on a farm 3 miles west of Salt Lake City. But by no
neans all of the soils in this lowland area contain excessive amounts of alkali,[a] especially
long Jordan River and adjacent to the border between the lowland and highland areas
here are thriving settlements.

The map and list of wells show general conditions. The wells are grouped along the
nargins of the area, and few are located in the interior. In general they are 2 inches in
iameter, but they vary in depth greatly. Although flows are obtained locally at only 30
eet below the surface, commonly they are not encountered above 150 feet. Perhaps the
verage well is between 200 and 300 feet in depth. It is a striking fact that flows may be
btained throughout the entire area at similar, but not at regular depths, indicating only a
ight inclination of the water-bearing horizons and their lenticular character. The flows
re usually small, averaging perhaps under 5 gallons a minute, though there are a number
f 15-gallon flows. The supply generally is reported rather constant, except that the
nallower wells are subject to seasonal variation. The pressure obtained, too, generally
small, being only enough to cause the water to rise either barely to the surface or a few
eet above. In general the pressure and the flow are reported to increase with the depth
ut measurements are not available. Both the flow and the pressure are considerable
n the deep Rudy well, sec. 5, T. 1 N., R. 1 W.

The conditions here noted apply mostly to the areas contiguous to the eastern and
outhern borders of the lowland west of Jordan River. Little information is available
oncerning the rest of this area (see list of wells pp. 59–75.) The few wells near Great Salt
Lake were sunk to unusual depths before flowing water was obtained, this being apparently
lue to the greater development of clay in that region, though no complete logs have been kept.
The well at the Inland Crystal Salt Company's works, in which, at a depth of 560 feet, water
was struck which rises about 9 feet above the surface and flows about 10 gallons a minute,
s reported 720 feet deep. Underground water in the Pleistocene deposits near the lake
contains considerable salt.

EAST OF JORDAN RIVER.

East of Jordan River the occurrence of underground water will be described under
he following heads: Salt Lake City, lowland area south of Salt Lake City, and upland
area south of Salt Lake City.

SALT LAKE CITY.

Salt Lake City is built principally on the floor of the main valley, but its outskirts
extend northward on the old delta of City Creek and eastward on the benches at the base
of the Wasatch Mountains. Adjacent to the highlands the underlying deposits are very
irregular in composition and distribution, consisting of sand and gravel with intercalated
streaks of clay. But toward the valley proper the conditions become more regular and
he prevailing clay is interbedded with sand and gravel, though from the records obtained
no definite sequence appears to be applicable to any considerable area.

In the lower part of the city marshy areas occur, but conditions there have been much
mproved since the early days of settlement. Formerly the lower channels of City, Red
Butte, Emigration, and Parleys creeks were ill defined and at high-water stage the part
of the city adjacent to Jordan River was a great slough. But by erecting embankments,
by confining the creeks to definite channels, and by draining the western part of the city
much of the swampy land has been reclaimed. Shallow ground water, except on the
benches, generally lies within 10 feet of the surface.

The line separating flowing and nonflowing wells skirts the lower benches, so that in
he larger part of the area occupied by the city artesian wells are obtained. Flows are found

[a] Soil survey in Salt Lake Valley: Bull. U. S. Dept. Agric. No. 64, 1900. Reclamation of Alkali
lands: Fifth Rept. Bureau of Soils, 1903, p. 1144.

at different horizons from about 50 feet downward, a common depth of wells being between 100 and 300 feet. The deepest well is that of the Rio Grande Western Railway Company near its station, the record of which appears on page 42. This well is 4 inches in diameter and 1,073 feet deep. It was put down in 1895 and 15 horizons were passed through from which flows were obtained. At a depth of 1,048 feet the greatest flow occurred, amounting to 78 gallons a minute at 4 feet above the surface and to 37.5 gallons at 25 feet above.

The most notable group of wells in this vicinity is that put down by Salt Lake City adjoining Liberty Park. There are 16 or more of these ranging from 2 to 9 inches in diameter and from 100 to 600 feet in depth. About half a dozen different water-bearing horizons, each furnishing a flow, are said to have been encountered in driving the wells. The greatest pressure reported caused the water to rise in a pipe 35 feet above the surface. Discharge measurements, as furnished by the city engineer, are given in the following table:

Discharge of city wells near Liberty Park, Salt Lake City.

No. of well.	Diameter.	Date of measurement.			No. of well.	Diameter.	Date of measurement.		
		Aug. 10, 1890.	July 17, 1900.	Sept. 29, 1902.			Aug. 10, 1890.	July 17, 1900.	Sept. 29, 1902.
	Inches.	*Gallons.*	*Gallons.*	*Gallons.*		*Inches.*	*Gallons.*	*Gallons.*	*Gallons.*
1....	9	201,600	120,000	96,941	10....	2	43,200	38,000	35,644
2....	9	180,000	297,000	60,588	11....	2	33,230	19,000	15,892
3....	8	279,132	280,000	302,940	12....	2	36,000	16,000	14,213
4....	8	.....	215,000	193,882	13....	2	54,000	35,000	20,626
5....	8	59,040	5,000	11,459	14....	2	.....	18,000	13,316
6....	2	14,400	10,000	5,876	15....	9	.....	98,000	36,172
7....	2	16,000	1,000	610	16....	2	.....	6,000	2,844
8....	2	27,000	500	206					
9....	2	54,000	25,000	19,784			997,602	1,183,500	830,993

In the immediate vicinity of these wells there are a number of springs whose supply is maintained chiefly by seepage. The combined flow from these springs and wells is estimated to amount to a maximum of 2,500,000 gallons a day. In order to utilize this supply in the city mains a pumping plant would have to be installed, and a further disadvantage is the doubtful quality of the water. At present this source is used for street sprinkling and for feeding the lake in Liberty Park (Pl. I).

In the northern part of Salt Lake City several thermal springs occur, the most conspicuous of which are the hot and warm springs. The hot springs issue at a temperature of about 130° from the Wasatch limestone at the western end of the spur of the mountains, with a discharge of about three-fourths second-foot,[a] and flow into Hot Springs Lake. The warm springs issue from unconsolidated deposits at the base of the spur about 2 miles southeast of the hot springs. The water is pumped to a slight elevation, from which it is piped to a sanitarium, the amount delivered being reported to average 350 gallons a minute. The temperature is 118° at the springs and about 100° at the sanitarium. Several other similar, but less important, springs occur, associated with the great Wasatch fault, along the base of the mountains between hot and warm springs.

The municipal water supply of Salt Lake City is derived from mountain streams and distributed through city mains. From this source there is an excellent supply of pure water under good pressure. The chief near-by available streams are City, Red Butte, Emigration, Parleys, Mill, Big Cottonwood, and Little Cottonwood creeks. The discharges of some of these are given on pages 19–22. None of these except City Creek is entirely controlled by the city. Red Butte Creek is reserved for the army post at Fort Douglas, Emigration and Parleys creeks partly contribute to the city supply, and the others are used entirely for

[a] Measured by A. F. Doremus.

ation and domestic purposes, under water rights owned by farmers. In order for Lake City to utilize these streams it must buy the water rights or exchange with the ers an equivalent amount of water obtained either from Utah Lake or from pumping ts.

e present public supply accordingly is obtained from City, Parleys, and Emigra- creeks. The watershed of City Creek is protected from forest fires and from contam- ion, and many of its springs are developed. The flow is distributed from settling tanks the mouth of the canyon and from a reservoir on Capitol Hill having a capacity of oximately 1,000,000 gallons. The surplus waters of City Creek are allowed to escape ugh flood ditches. Water from Parleys Creek to the extent of 81.8 per cent of its flow been obtained by Salt Lake City in exchange for an equivalent amount of water from h Lake delivered through the Jordan and Salt Lake City canal. A settling reservoir, ling somewhat less than 1,000,000 gallons has been constructed at the mouth of Parleys yon, whence the water is conducted through a concrete conduit to a storage reservoir a capacity of about 5,000,000 gallons situated on Thirteenth East street. An addi- al supply is obtained from a trench in the bed of Emigration Creek half a mile above mouth of the canyon. This trench is approximately 150 feet long, 10 feet wide, and eet deep. It was dug in sand and gravel in the bed of the creek and at right angles to ourse. A supply estimated to amount to 1,000,000 gallons a day is thus obtained, which ped to the Thirteenth East street reservoir.

o direct record is kept of the amount of water used by Salt Lake City, but discharge surements of the creeks at the mouths of the canyons show the amount available. is insufficient during the dry months and the use of water is restricted to a per capita umption of 120 gallons a day, although it is considered desirable, in this dry climate, e lawns and gardens have to be irrigated, to maintain a per capita supply of approx- ely 300 gallons a day. It is planned to obtain in the immediate future a portion of the of Big Cottonwood Creek, by exchanging therefor water from Jordan River, delivered ugh the City canal, as is being done in the case of Parleys Creek, and to make the new ly available by constructing a pipe line from the mouth of Big Cottonwood Canyon to nouth of Parleys Canyon, a distance of about 7 miles.

SOUTH OF SALT LAKE CITY.

wland area.—It will be convenient to divide the area south of Salt Lake City into a nd and an upland portion, taking as the dividing line that which separates flowing nonflowing wells. Pl. VIII shows that this line extends contiguous to, but below, Jordan and Salt Lake City canal as far as Little Cottonwood Creek, after crossing h it turns westward to the flood plain of Jordan River. The lowland area is traversed arleys, Mill, Big Cottonwood, and Little Cottonwood creeks, which flow in open valleys, broad and low intervening divides. The general aspect of the country is that of a tly dissected plain that rises gently toward the upland terraces. This area is relatively ly populated, and intensive farming is widely practiced.

e detailed character of the underlying lake sediments is not satisfactorily known, but the well records conditions appear to be similar to those found elsewhere in the under consideration. Beneath the lowlands the stratigraphy is more uniform than r the base of the mountains; fine-textured sediments are more abundant than coarse, clay predominates. But a comparison of available well records fails to establish a lation between the different beds of sand and gravel throughout the lowland. Well rs state that all logs are different, and yet that, on the whole, general sections persist ertain areas in which the differences are minor. It is believed that the sediments toward Jordan River at about the same angle as does the surface. The best-defined nce that has been reported occurs immediately south of Salt Lake City, where in al light-colored clay at the surface overlies blue clay ranging from 30 to 70 feet in ness, beneath which water-bearing sands and gravels occur at a depth of about 100

feet. At greater depths the succession appears to be more variable, but there are few satisfactory well records.

Ground water now lies within 10 feet of the surface over practically the entire lowland area, but it is reported that in the early days it did not lie so near over so large an area. Present conditions are largely due to irrigation. Several old residents state that below the level of the Jordan River canals the ground-water surface has locally risen 40 or 50 feet since their construction. It has already been mentioned that along several of the drainage ways seepage water reappears at the surface and occasionally forms considerable streams, as at Spring Creek near its junction with Big Cottonwood Creek, where the September flow is estimated to amount to 14,000,000 gallons a day. In many places also, especially along the bases of benches, lines of seep springs occur that furnish considerable flows, a notable occurrence being those at the nursery in the southeastern part of Salt Lake City. But locally, as along the bluff east of Jordan River, north of the Bingham Junction smelters, the water appears at so low an elevation as to be of comparatively little use. When pumping becomes more generally practiced in the valley this ground water that lies so near the surface can be easily developed.

Flowing wells in this area are numerous. They are generally 2 inches in diameter and 100 to 400 feet in depth, and they commonly yield between 20 and 50 gallons a minute, though there are many variations. The pressure is low, generally less than 10 pounds. Well drivers say that their best results are obtained in belts extending northwest and southeast, parallel with the creeks, and that these productive belts are separated by relatively barren ones. The water-bearing sands and gravels apparently mark the courses of old waterways, while finer-textured material was deposited in the intervening areas. These distinctions have been noticed only in the upper parts of the lowland area, and near the river they are said to disappear. One of the best wells is at the plant of the American Smelting and Refining Company at Murray. It is 4 inches in diameter, 400 feet deep, and is reported to flow about 400 gallons a minute under a pressure of 3 pounds per square inch. The record of this well is given as follows, on the authority of H. F. Yeager, well driller:

Record of American Smelting and Refining Company's well at Murray.

	Thickness in feet.	Depth in feet.
Sand and gravel	5	0–5
Mud	3	5–8
Sand and gravel	4	8–12
Blue clay	6	12–18
Quicksand	10	18–28
Blue clay	8	28–36
Loose sand and gravel (good pump well at 42 feet)	16	36–52
Blue clay	8	52–60
Quicksand (flow at 63 feet)	6	60–66
Blue clay	18	66–84
Yellow clay	6	84–90
Loose sand and gravel (strong flow at 95 feet)	15	90–105
Yellow clay	3	105–108
Coarse gravel and rock (strong flow at 112 feet, and at this point the well at office stopped flowing)	8	108–116
Coarse gravel and rock	6	116–122
Quicksand	20	122–142
Clay, very hard	10	142–152
Quicksand	6	152–158
Gravel (small flow at 165 feet)	11	158–169
Hard pan, very hard	8	169–177
Blue clay	6	177–183
Quicksand (flow at 203 feet)	20	183–203
Quicksand	16	203–219
Blue clay	4	219–223
Quicksand	7	223–230
Blue clay	8	230–238
Quicksand	18	238–256
Blue clay and quicksand in layers 2 feet thick	22	256–278
Quicksand	8	278–286
Blue clay, very hard	12	286–298
River sand	2	298–300
River sand	7	300–307
Cemented gravel	12	307–319
Yellow clay	7	319–326
Cemented gravel	17	326–343
Loose gravel	23	343–366
Yellow clay	2	366–368
Gravel	7	368–375
Cemented gravel	12	375–387
Loose gravel	12	387–399

Decrease in flow and complete failure of some wells are reported throughout this area nd are especially apparent in the vicinity of Murray. These results are directly traceable › the increased number of wells that have been sunk in recent years and to the fact that ttle economy is exercised in the use of the water. Well owners should more fully realize nat the limited water supply comes from a common source, that the wastefulness of one ounteracts the prudence of another, and that the common interest of all demands that he supply be conserved.

Upland area.—The upland south of Salt Lake City includes the area lying between the ase of the Wasatch and Traverse mountains and the area in which flowing wells can be obtained. This region is characterized topographically by the abundance and perfection of development of shore phenomena which mark different stages in the history of Lake Bonneville. As on the western side of the valley, the upland is in general a plain that rises toward the base of the mountains, but is interrupted by benches and escarpments and deeply cut by the creeks flowing from the Wasatch Mountains.

The Bonneville terrace extends along the mountains like a narrow shelf, its horizontal lines contrasting strongly with the deep, vertical furrows on the mountains. Broad deltas formed by the larger creeks at the Provo stage extend down to the lowlands, and successive escarpments mark halting places in the retreat of Lake Bonneville. The most prominent of all the shore phenomena in the area covered by this report is the great embankment at the point of the mountains east of Jordan Narrows. Here the waves, gaining energy from the wide expanse of the old lake, carved a great sea cliff against the mountains and distributed the débris to form an enormous accumulation of sand and gravel.

Prominent local features of this upland belt are the relics of glaciers adjacent to the mouth of Little Cottonwood Canyon and the evidences of recent faulting along the base of the mountains. Little Cottonwood Creek in Pleistocene time was occupied by a glacier which carved a broad U-shaped valley and deposited lateral and terminal moraines composed of a heterogeneous mass of coarse- and fine-textured débris. Along the entire front of the Wasatch Mountains Gilbert has found indications of recent dislocation associated with the great Wasatch fault. The evidence is varied, but escarpments in unconsolidated material breaking the even trend of alluvial slopes are conspicuous.

The underlying deposits of the upland are mostly coarse textured, being near their origin, nd consist chiefly of sand and gravel. The creeks, where they have cut deeply, expose ood sections, but few deep-well records were obtained.

This region in general is thinly populated, but where water is available there are settlements, nd wherever the canals extend there are thriving farms. The contrast between the ourishing area which is supplied with water and the dry, barren region is striking. The ap shows the distribution of the principal canal systems, which are supplied by the several eeks that flow from the Wasatch Mountains and by Jordan River. Underground water used only to a limited extent. Pl. VI and the list of wells illustrate conditions. Underound water is recovered chiefly in the lower (western) part of the upland, where it lies at pths ranging from the surface to 50 feet below. In this productive area both dug and iven wells are used. The driven wells are commonly 50 to 200 feet in depth, and water generally found beneath a bed of clay in sand or gravel under sufficient pressure to cause to rise within pumping distance of the surface.

In the eastern part of the upland area ground water generally lies at a greater depth than feet below the surface, and in a number of places has not been found in test wells over 0 feet deep. In this (eastern) division of the upland, where the greater part of the valley posits are coarse textured, the ground water sinks deep before a relatively impervious d is encountered, and then it tends to move to the lower part of the valley. Away from e influence of seepage from the creeks little water is supplied to this area. Between the eeks the chief source of supply is seepage from the mountains. The most likely localities r sinking wells are along the courses of waterways, but over a large part of the upland the ospect is poor for obtaining underground water in quantity within easy reach of the surce. *In the mouths of the canyons* there is the chance of developing the underflow by

subsurface dams or by tunnels, mentioned on page 40. Other favorable localities for prospecting are adjacent to the base of the mountains, where water may be had by developing springs and by tunneling into the bed rock.

Seep springs occur at several localities along the base of the mountains south of Salt Lake City, the most important, perhaps, being those about midway between Mill and Big Cottonwood canyons. The feeble springs there issuing from sand and gravel were formerly allowed to go to waste, but by developing them a flow of about 2 second-feet was obtained, and a considerable tract of land thus became available for agriculture. About 4 miles southwest of the town of Draper, in sec. 12, T. 4 S., R. 1 W., at some distance from the base of the mountains, there are four warm-water lakes that are fed by springs, some of which are said to be quite hot. The westernmost of the group is the largest and covers an area of about 5 acres. The temperature is reported to remain at about 70° the year round.

Since underground water is so scarce beneath the upland, the most efficient manner of developing this area appears to be by the use, as suggested above (p. 38), of creek water in high-level canals to a greater extent than is now practiced.

UTAH LAKE VALLEY.

The following description of the occurrence of underground water in the valley of Utah Lake begins at the north and proceeds east, south, and west around the lake, the several towns affording subheadings for convenient reference. (Pl. VIII.)

LEHI AND VICINITY.

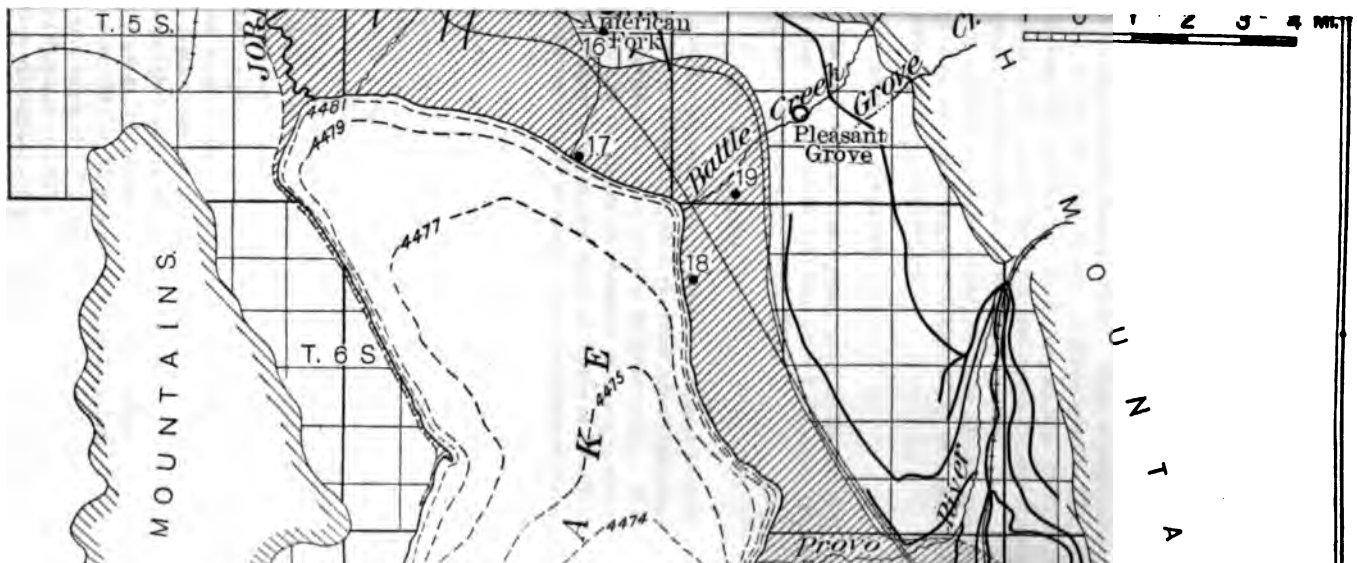
Lehi is situated in the main valley at some distance from the distinct terraces. Dry Creek lies adjacent to the town, but, as its name signifies, the creek, after supplying a number of irrigation ditches, usually carries little or no water in its lower course. There is no public water system in the town, and the supply for domestic purposes is derived from numerous wells. A few shallow dug wells tap ground water at depths of 5 to 30 feet, but the majority are deeper and reach water under pressure. The sugar-plant mill pond is fed by springs and is an important local source of supply.

Lehi was one of the first towns where artesian water was found in the Bonneville area, flowing wells having been obtained there about 1880. Formerly a feeble first flow was found in gravel about 60 feet from the surface and a stronger supply at a depth of about 160 feet, but in recent years flows, even from the second horizon, have failed during part of the season in consequence of the increased use of artesian wells in the area nearer the lake, and at times pumping has to be resorted to. However, when water does not actually flow it rises in the wells to within a few feet of the surface.

The general section in the vicinity of Lehi, as reported by H. C. Comer, shows blue clay to a depth of 50 or 60 feet. Below this is the first water bed, consisting of about 50 feet of sand and gravel, separated from the second water horizon by 40 feet of light clay. This section does not apply in the eastern part of the town, where the log of the San Pedro Railroad well shows coarse-textured material within 100 feet of the surface. In this well the main supply is derived from a depth of 330 feet, the water rising to within a few feet of the surface. These two logs illustrate the variability of adjacent sections.

The Utah Sugar Company's plant at Lehi has several 2-inch wells, and the following flows in gallons per minute are reported: 80 feet, 15 gallons; 120 feet, 25 gallons; 150 feet, 20 gallons. Logs of these wells were not kept. The Rio Grande Western Railway well near the sugar factory is 3 inches in diameter and 165 feet deep. The water is reported to rise in a pipe to a point 30 feet above the surface and to flow about 50 gallons a minute at the level of the ground.

Toward Utah Lake, below Lehi, there is a considerable development of flowing wells from which a number of square miles are irrigated. In this district there are several hundred flowing wells which average about 150 feet in depth. A close relationship has been established between the flow of the wells in the fields below Lehi and those in town.


T. 5 S.
T. 6 S.
MOUNTAINS
American Fork
Battle Creek
Pleasant Grove
Provo River
4481
4479
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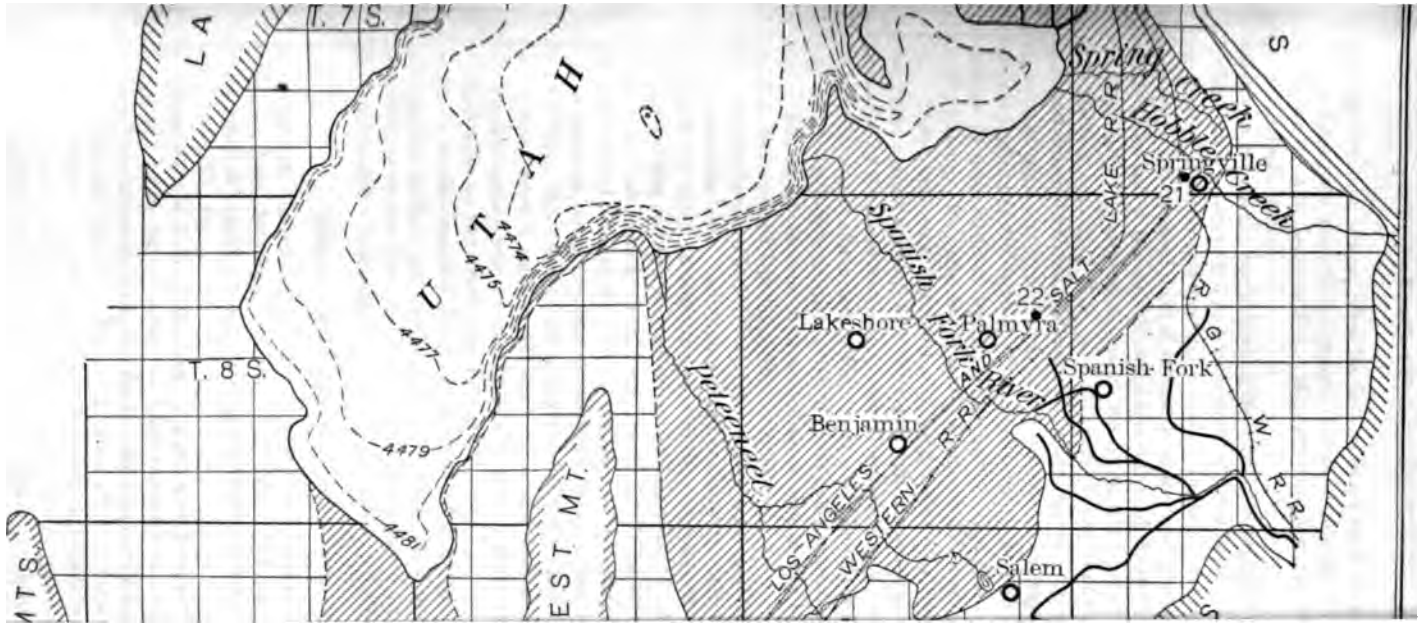
T. 7 S.
T. 8 S.
L A
U T A H
L E S T M T.
4474
4475
4477
4479
4481
Spring Creek
Hobble Creek
Springville
21
LAKE R.R.
Spanish Fork River
22
SALT
Lakeshore
Palmyra
Spanish Fork
Peteetneet
Benjamin
LOS ANGELES WESTERN R.R.
Salem
R.G. W. R.R.

ring the irrigation season, when the field wells are all flowing, those in Lehi practically p, but during the winter it is a general custom to plug the wells used for irrigation, after ich those in town begin to flow. Measurements have not been made, but the general ts are well established.

Northwest of Lehi the line separating the areas of flowing and nonflowing wells continues Jordan River, reaching it 3 to 4 miles north of Utah Lake. The line extends about half nile west of the river and approaches close to the northwest corner of the lake near Sara- ga Springs. In the flood plain of Jordan River flows can probably be obtained continuing o Salt Lake Valley, but outside of the line indicated the surface elevation is too great.

The Salt Lake City authorities, about 1890, sank a number of wells in the flood plain of dan River in sec. 12, T. 5 S., R. 1 W., with the object of increasing the supply of the dan and Salt Lake Canal. These wells, about 130 in number, were mostly 2 inches in meter, though a few were 6 inches, and are said to average 100 feet deep. Clay was countered down to the bottom of the wells, which were in gravel. It is stated that ter rose in pipes 30 to 40 feet above the surface, and that individual wells flowed 125 llons a minute. It is also stated that the combined flow amounted to 3,000,000 gallons lay. These wells soon interfered with neighboring ones, stopping their flow, and suit s brought against the city, with the result that the municipality was compelled to plug its wells. After these had been plugged for some time a number of them were tempo- ily opened, and in about twenty-four hours thereafter the water in one of the wells, the w of which was interfered with, situated about half a mile above the city wells, had fallen feet. The city wells were then capped again and in five hours the water in the well erred to had regained 7 inches of its lost level.

Near the northwestern end of Utah Lake there is a group of hot springs which occur both shore and in the lake. On the shore there are several springs which support the Saratoga ort where the water, having a temperature of 111°, issues through the lake deposits and used for bathing and to a limited extent for irrigation. In the summer of 1904, during e survey of Utah Lake by G. L. Swendsen of the Reclamation Service, three groups of rings were found beneath the water of the lake. Their existence was shown by the pres- ce of depressions occupying areas of 100 square feet to 3 acres in extent and having depths 20 to 80 feet. Since the prevailing depth of the lake is much less and the bottom is com- sed of slimy mud, a considerable discharge is thus indicated. Hot water that flowed ove the lake surface was obtained by sinking pipes a short distance into the bottom.

About 5 miles up Dry Creek from Lehi is the town of Alpine, located near the mouth of e canyon on the dissected Bonneville terrace. The settlement is supplied with water m irrigation ditches, and possibly not more than half a dozen wells have been sunk. ese are 25 to 80 feet deep, and the water level is reported to vary considerably between nter and summer. Springs occur in Dry Creek Canyon, but they have not been developed.

AMERICAN FORK, PLEASANT GROVE, AND VICINITY.

The towns of American Fork and Pleasant Grove receive their main water supplies, pectively, from American Fork and from Battle and Grove creeks. These streams d a number of irrigation canals, and are the chief source of underground water in this inity. (Pl. IX, *B*.)

American Fork is built at the base of a series of terraces on both sides of American rk (creek), which has cut a narrow channel through the old lake deposits. Ascending e valley from American Fork, five distinct terraces can be traced up to the broad Provo ach, between which and the Bonneville level, which forms a shelving bench against the untains, traces of shore lines of pre-Bonneville age have been reported. In its lower urse American Fork is dry throughout most of the year in consequence of the draft on its waters for the canal system which supplies the uplands.

Shallow wells in American Fork are commonly less than 50 feet in depth, averaging sibly 25 to 30 feet, and the ground-water level is reported to vary 10 to 15 feet between e winter *minimum and summer* maximum. The water generally is found in gravel.

Deep wells have been sunk in the extreme southwestern part of the town in search of flowing water. The water rises in these nearly to the surface, and furnishes the main supply for domestic purposes. Well records show a variable succession of sand and gravel with comparatively little clay. The city well is typical, and probably is the deepest in this vicinity. It is 440 feet deep and 6 inches in diameter. Two principal water horizons are reported, at 240 and 340 feet, and the water stands in the well at a depth of 2 feet. An electric motor pump supplies water for public purposes, but there is no waterworks system. Individual families or groups of families maintain their own wells.

The line separating the areas of flowing and nonflowing wells as mapped between Lehi and Pleasant Grove lies contiguous to the San Pedro Railroad, and here, as elsewhere, ground water commonly lies within 10 feet of the surface. Extensive areas of marshy land lie contiguous to the lake shore, where conditions have grown worse since the introduction of irrigation. The flowing wells in this vicinity vary in depth, but are commonly about 100 feet deep. As Utah Lake is approached more nearly uniform conditions are revealed by the logs. Clay is commonly present at the surface and continues to a depth of 90 or 100 feet, below which the water-bearing gravel occurs. In the deeper wells alternating sand, clay, and gravel are reported below the first gravel, and flows are obtained from every coarse-textured bed. One of the best wells in this vicinity is in sec. 23, T. 5 S., R. 1 E. It is 147 feet deep, 2 inches in diameter, and throws a stream 3 feet 8 inches above the pipe, having a capacity, therefore, of about 150 gallons a minute.

A disturbed belt of rocks, dipping eastward, and locally covered by débris, lies near the foot of the Bonneville terrace between American Fork and Grove creeks. Springs occur at about this horizon, and prospecting for water in this belt, in sec. 17, T. 5 S., R. 2 E., has brought notable results. William Wadley & Sons, by tunneling into bed rock, have developed enough water to irrigate a number of acres of fruit land, which is bringing in handsome returns. Several tunnels have been dug, the most important of which lies about 200 feet below the Bonneville level and was driven 318 feet through black shale into broken and cavernous gray limestone, in which the water occurs.

Pleasant Grove is located on alluvial slopes formed by Battle and Grove creeks. Its situation is so high that flowing wells can be obtained only in the extreme lower part of the town, which depends for its chief underground supply on wells from which water has to be pumped. Ground water can usually be obtained at 10 to 50 feet from the surface. No regular sequence of deposits underlies the town, but a variable succession of clay, sand, and gravel is encountered in wells, the water horizon usually being underlain by clay. In the southeastern part of Pleasant Grove no successful wells have yet been obtained, though prospecting for them has extended to a depth of 100 feet; not deep enough to find an impervious stratum. A continuous succession of gravel beds is reported.

The high, almost flat Provo delta between Pleasant Grove and Provo is scantily provided with water. The surface is generally gravel covered, and gravel is commonly found in wells to depths of 30 to 60 feet, below which sand is reported. Only a small amount of clay appears to be present. This tract of land is well adapted for the cultivation of fruit, but the present supply of water is insufficient for its complete development. Water was first brought to the delta by canals from Provo River in 1868, and the present supply, whereby a maximum diversion of about 116 second-feet is obtained, was established in 1888. Before irrigation was practiced on the bench the depth to ground water was considerably greater than it is now. Old wells are over 100 feet deep, but of late years the ground-water surface has risen so that on a large part of the area water can be obtained in wells averaging 50 to 75 feet deep. Toward the lower margins of the bench the depths to ground water is less than 50 feet. Here, as elsewhere throughout this entire area, ground water is lowest in the winter and highest during the irrigation season. The annual variation on Provo bench appears to range from 5 to about 17 feet. A few examples will illustrate general conditions. In 1875 a dry well 100 feet deep was dug in sec. 14, T. 6 S., R. 2 E. In the same section, during the winter of 1878-79, N. Knight dug a well 110 feet deep which afforded 3 feet of water in winter and 15 to 20 feet in summer. In 1899 N. J. Knight

A. VALLEY OF PROVO RIVER BELOW MOUTH OF CANYON, LOOKING NORTH.

Shows Provo Bench and Bonneville terrace.

B. AMERICAN FORK AT MOUTH OF CANYON.

third well only 60 feet deep, near the second, which afforded about 3 feet of water
er and 20 in summer.[a]

ing wells can not be obtained on the bench because of its elevation, though several
ts have been made, without success. In 1887 and 1888 two deep wells were driven
same section as those just referred to. The Colorado Fish Company put down a
well 250 feet deep and obtained water which rose to within 80 feet of the surface.
as pumped for several years. In 1888 Mr. Knight drove a 2-inch well 300 feet
which water rose to within 90 feet of the surface. Both of these wells are now
ned.

n Provo to Pleasant Grove along the narrow belt of lowland lying between Provo
and Utah Lake there is an abundance of underground water. The line that sepa-
owing and nonflowing wells coincides approximately with the San Pedro Railway,
also marks roughly the upper limit of the area in which ground water lies within
of the surface. Between the railroad and the base of the bench few wells have
driven and little is known of the conditions, but it is thought that water can be
ed at depths of 10 to 50 feet.

iguous to the railroad a number of feeble seep springs occur along the base of a
uff between which and the lake the ground is almost flat. Water occurs on the
in many places, rendering the land unfit for use. Before irrigation was so exten-
practiced it is reported that this lowland belt was fertile farming land, but in late
due to the rise of the ground-water level, the land has materially decreased in value.
erable areas of available land, however, are yet to be found in this area, and flowing
are used to irrigate several hundred acres. Conditions can be much improved by
ge. The map and list of wells show the general conditions. The deep wells in
elt average slightly over 100 feet and generally are 2 inches in diameter. North
vo River the yield is inconsiderable, averaging, possibly, less than 15 gallons a minute
ell; but in the vicinity of Geneva, a resort on the lake below Pleasant Grove, the
of Battle Creek drainage is experienced, and some of the strongest wells of the entire
overed by this report occur. Harry Gammon's wells, in sec. 7, T. 6 S., R. 2 E., are
the best. One of these is 3 inches in diameter, 110 feet deep, and yields a flow of
266 gallons a minute, the water rising in a pipe to approximately 28 feet above the
e. The section in this vicinity is shown on Pl. V, the water occurring in gravel in
ttom of the well.

PROVO AND VICINITY.

vo derives its water supply from Provo River. A number of canals tap the river
own on the map, Pl. VIII), and distribute a good supply to the town; and water
usehold purposes is delivered through city mains from a direct source in the river
he mouth of the canyon. The quality is unsatisfactory, however, and a new system
g installed whereby a better supply is obtained from a number of springs that issue
nconsolidated débris along the base of the canyon for several miles above its mouth.
l records show fairly uniform stratigraphic conditions about Provo. Gravel usually
lies the surface to a depth of from 10 to 20 feet, and is succeeded by 20 to 30 feet of
below which is a considerable thickness of clay, averaging possibly 100 feet, the
20 or 30 feet of which is yellowish and the lower part blue. Underlying the clay a
gravel occurs, which is said to be underlain by clay, though about Provo it has sel-
een penetrated. With minor variations this section appears to hold good over a
part of the territory adjacent to the east shore of Utah Lake. Northwest from Provo
rface gravel disappears, but clay, light above and dark below and underlain by sand
ravel, is reported in the vicinity of Geneva, American Fork, and Lehi. South of
, in the vicinity of Springville, similar conditions prevail. (Pl. V.)

[a] se facts were obtained from Mr. Caleb Tanner, to whom the writer is indebted for many
ies.

The beds about Provo appear to dip toward the lake at a low angle, approximately corresponding to the slope of the surface, this being indicated by the fact that the depth at which the water-bearing gravel is found over large areas is approximately constant. In the vicinity of Provo some direct data were obtained on this point. Wells have been driven along Center street from Academy street in Provo westward to the shore of the lake. The depths at which the top of the gravel was struck in some of these wells was obtained from the driver, J. Westfall, and a line of levels was run along the surface by the United States Reclamation Service, from which it appears that the lakeward inclination of the gravel is approximately 9 feet per mile, the rate decreasing as the lake is approached. Similar conditions probably exist throughout the area studied, the slope being greatest near the mountains, while beneath the broad lowlands the strata lie more nearly horizontal.

Ground water in the vicinity of Provo can generally be obtained in the upper gravel within 10 feet of the surface. In the vicinity of the lake the gravel disappears and clay generally occupies the surface. Here, as is so general throughout the entire area, swampy conditions prevail, owing to the lowness of the region, the recession of the lake, and the rise of ground water due to irrigation.

Flowing wells exist in great number in this well-populated region, and in general an abundance of good water is obtained within 200 feet of the surface. The main water-bearing horizon is the bed of gravel that underlies the blue clay. Water is generally reached in this gravel at 150 to 200 feet from the surface, but conditions are not absolutely uniform at all places, and where the prevailing section is varied by local streaks of clay, sand, and gravel corresponding differences exist. Feeble flows are sometimes found at 100 feet, and a few wells obtain water from a depth of 360 feet, but this depth is unusual in the vicinity of Provo. The wells about Provo are generally 2 inches in diameter, and their flow may possibly average 50 gallons a minute. Among the best wells in this vicinity are those at the stations of the San Pedro, Los Angeles and Salt Lake Railroad and the Rio Grande Western Railway. These are 3 inches in diameter and 190 and 176 feet deep, respectively. In November, 1904, the Rio Grande Western well was found to flow approximately 12 gallons a minute at 2 feet above the surface under a pressure of 15½ pounds per square inch.

SPRINGVILLE AND VICINITY.

Between Provo and Springville the lowland contiguous to Utah Lake extends to the Rio Grande Railroad, above which the surface rises at a steep grade to the base of the mountains. The lowland for the most part is marshy, and the line that separates flowing and nonflowing wells lies only a short distance east of the railroad. A low scarp, which apparently marks a Pleistocene fault, can be traced immediately west of the county road for a mile or more beyond the Utah County Infirmary toward Springville. Springs occur at the base of the scarp, and the large springs at the head of Spring Creek may be associated with faulting. A number of small lakes mark the presence of these springs, and Spring Creek, whose main supply is thus derived, flows about 1,600 second-feet.

The deepest well in this area is that of the infirmary, situated near the road about midway between Provo and Springville. The well is 3 inches in diameter and 270 feet deep and water is reported to rise in a pipe to a point 3 feet above the surface, flowing about 50 gallons a minute. In this vicinity a feeble first flow is reported at depths of 65 to 80 feet.

Springville is situated on the plain about 3 miles below the mouth of Hobble Creek Canyon, the channel of the creek passing through the town. During the irrigation season practically all of Hobble Creek water is diverted by canals that head near the base of the mountains.

Ground water in Springville is obtained from wells that usually range in depth from 25 to 30 feet, the water occurring in the top gravel. The general level of ground water in the town is reported not to have changed since the early days, and only an annual difference of a few feet is noticed between winter and summer conditions.[a]

[a] Stevenson, J. B., well driver.

Records of wells in the vicinity of Springville show rather uniform conditions. The town enerally is underlain by gravel 5 to 40 feet thick, below which blue clay occurs to a epth of about 130 feet, underlain by sand and gravel down to 180 feet; then about 50 et of light-colored clay is encountered, followed by sand and gravel at a depth of about 0 feet. In the area nearer the lake the top gravel generally is wanting, but otherwise nilar sections are reported in that locality.

Flowing wells are obtained from the two lower gravel horizons at depths of approxiately 130 and 230 feet. The common occurrence of water at these two horizons implies usual uniformity of underground conditions, and suggests a low lakeward dip, approxiately corresponding to the surface inclination. The wells are commonly 2 inches in diamr, though a few are 3 inches, and they yield on an average possibly 20 to 50 gallons a nute. One of the best in Springville is a 3-inch well belonging to A. Cox. It is 230 feet ep, flows about 120 gallons a minute, and its water is reported to rise in a pipe to a point feet above the surface. The Rio Grande Railway Company has two wells in Springle, which are 216 and 304 feet deep. In the deeper the first flow was struck at 126 feet, econd at 216, a third at 260, and a fourth at 292. The shallower well is 3 inches in diamr, and is reported to flow about 200 gallons a minute at the surface, which is reduced to out 12 gallons a minute at the top of a tank about 30 feet above the surface.

Mapleton Bench is the local name for the Provo Delta, lying between Spanish Fork and obble Creek. The delta is here prominently developed, and constitutes valuable farmg land. Flowing wells are not obtained on Mapleton Bench because of its elevation, but ere are a number of dug wells. It is reported that in the early days the wells on the nch were 60 feet or more in depth, but since irrigation has been practiced the groundater level has been considerably raised, and now the wells average possibly only 30 feet depth. There is a marked difference in the depth to ground water in winter and sumer, the range in some instances amounting to over 10 feet. Along the outer margin of e bench there is a line of springs, many of which did not exist before the ditches were g. Big Hollow Creek, a stream that flows from the bench about 2 miles south of Springle, is a conspicuous example. In the early days scarcely any water is said to have wed in its channel, whereas it now irrigates over 100 acres.

Considerable amounts of water are obtained by a few tunnels that have been dug along e eastern edge of Mapleton Bench. The entrances to the tunnels are commonly at the es of springs. Some begin and end in unconsolidated materials, while others penetrate d rock. The longest noted is in sec. 24, T. 8 S., R. 3 E. Its length is 275 feet. Water ough to irrigate about 100 acres comes through crevices in bed rock.

SPANISH FORK, PAYSON, AND VICINITY.

The town of Spanish Fork is situated on the general lowland at the base of Mapleton ench and immediately north of Spanish Fork, about 5 miles below the mouth of its nyon. From the few well records available it appears that sand and gravel comonly underlie the surface to a depth of about 30 feet and are succeeded by 150 feet of ay, below which water-bearing gravel is usually encountered at a depth of 180 feet. The g of the well recently completed at the San Pedro station, about a mile west of the town, ows a greater thickness of clay, amounting to 205 feet, beneath which sand and clay were und to 390 feet, where water-bearing gravel occurs.

Spanish Fork is rather poorly supplied with underground water. Dug wells commonly ach water at depths ranging from 10 to 25 feet, but its quality is not good. Flowing lls were formerly obtained, but in recent years the flows generally have ceased and pumpg has to be resorted to. A city waterworks system was installed in 1904, the supply ing derived from Evans Spring, near the mouth of Spanish Fork Canyon, about 5 miles ove the town, and an excellent supply is now available. The line separating flowing d nonflowing wells now lies in the extreme northwest corner of the town. The first flow urs at a depth of about 180 feet and a second flow between 350 and 400 feet. The cream- well, 2 inches in diameter and 220 feet deep, is typical. Water was struck at 180 feet

which in 1900 flowed 9 gallons a minute, while in 1904 it stood about 4 feet below the surface with little or no variation. In 1904 the San Pedro, Los Angeles and Salt Lake Railroad Company put down a well 415 feet deep at its Spanish Fork station and obtained a flow of 36 gallons a minute through a 2-inch pipe from gravel in the bottom of the well.

Between Spanish Fork and the Goshen divide there are a number of settlements that are adjacent to the line separating flowing and nonflowing wells.

Salem is situated at the lower end of the Provo Bench, about midway between Spanish Fork and Payson. In the northwestern part of the town the water table lies close to the surface and throughout the greater part of the settlement water can be obtained within 10 feet of the surface. There are many springs, the most important of which supply Salem Pond, which covers about 13 acres and averages possibly 12 feet in depth. The line separating flowing and nonflowing wells passes about midway through Salem. The flowing wells are generally feeble and the quality of the water is poor. A first flow is commonly obtained at about 160 feet and a second at about 250 feet.

Payson is situated on and near the delta formed by Peteneet Creek at the Provo stage of Lake Bonneville, part of the town being built on the delta and part on the subjacent plain. Flowing wells are not obtainable because of the elevation, and the underground water supply is furnished by dug wells. These vary considerably in depth because of the irregular distribution of the delta deposits. Their depth ranges from 15 to 115 feet and probably averages between 30 and 40 feet. As an instance of local variation it may be mentioned that in one well ground water is obtained at 18 feet while on the opposite side of the street a well was dug 90 feet without encountering water. The level of ground water is reported to fluctuate but little. A number of families in Payson are supplied by pipe lines, the water being derived from tunnels driven into the base of the bench.

The town of Spring Lake is situated near the base of the mountains. The line separating flowing and nonflowing wells passes along the foot of the Provo Bench and lies about half a mile west of the town. In this locality ground water is found commonly within 10 feet of the surface and there are a number of shallow wells, but the chief supply comes from springs. Spring Lake covers an area of about 12 acres and discharges a stream of about 2 second-feet. It is made by damming a small creek that is fed by springs. Springs occur in the vicinity of the base of the mountains between Spanish Fork and Spring Lake. Most of them appear to be seep springs, but some that lie near faults that adjoin the base of the mountains may be of deeper seated origin. Many of the springs flow 20 to 50 gallons a minute.

Santaquin is built on a delta of Santaquin Creek, near the base of the mountains, far above the general level at which flowing wells are obtained. The town is chiefly supplied with water for both household and irrigation uses by Santaquin Creek, and only a few wells have been dug. About a dozen wells strike water in gravel at depths of between 15 and 25 feet on a low bench in the southeastern part of the town. Tunnels are also dug into this bench, from which two pipe lines supply a number of families with water. Below the bench in Santaquin there are very few wells; two had to be dug about 80 feet before water was obtained.

Below the line separating flowing and nonflowing wells between Hobble and Santaquin creeks the valley plain slopes gently to Utah Lake. Throughout this area ground water lies within 10 feet of the surface, and adjacent to the lake and in certain isolated localities swampy conditions occur. This area is mostly underlain by clay, which is reported to predominate in all of the wells. Little or no gravel is encountered in well driving and the layers of clay alternate with layers of sand. Few satisfactory well records from this region have been obtained, and no correlation of the underground deposits has been possible. Different conditions seem to exist in neighboring wells, indicating a lenticular arrangement of the deposits.

The towns of Palmyra, Lake Shore, and Benjamin are situated below the line of flowing wells. Many farms are scattered over this area, but in a few localities—north of Spanish Fork, for instance—alkali is so prevalent as to discourage settlement. Much of the water used in irrigating this tract is derived from canals supplied by Spanish Fork, but flowing wells also are used to a considerable extent.

Flowing wells have been obtained throughout this area at depths of 50 to 500 feet, as shown by the list. Flows are usually found in every considerable bed of sand encountered in drilling, and six or more water-bearing beds are sometimes struck in a 400-foot well. Shallow wells are not the rule in this region, for, though many are 150 to 200 feet deep, the majority are nearer 400 feet deep. Because of the general absence of gravel and of persistent beds of sand there are few especially good wells. The flows obtained are generally under 50 gallons a minute and frequently are less than 10. The pressure is low, seldom being sufficient to cause the water to rise more than a few feet above the surface.

At the southern end of the lake, north of West Mountain, just above low-water level there is a warm spring that was estimated to flow 200 gallons a minute. Its temperature is 88°.

GOSHEN VALLEY.

Goshen Valley can be divided into a highland and a lowland portion, a convenient line of division for present purposes being that which separates areas where ground water lies above 10 feet from the surface, from those in which it lies below that depth. The highland lies contiguous to the mountains and merges into the lowland which adjoins the lower course of Currant Creek and the southern extremity of Utah Lake. The lowland is chiefly underlain by clay and the soils contain abundant alkali.[a] Throughout the entire area ground water lies close to the surface and marshy conditions exist, especially toward the lake.

The area of flowing wells in Goshen Valley embraces about 15 square miles and extends from Utah Lake to within about a mile of Goshen. Within it flowing wells are obtained at depths ranging from 50 to 400 feet. From the few available records it appears that varying stratigraphic conditions exist in this area, the prevailing clay being irregularly interbedded with sand, usually in thin streaks, with very little gravel. The flows obtained are small, averaging possibly about 5 gallons a minute, and the pressure is sufficient to cause the water to rise only a few feet above the surface.

Goshen itself is furnished with surface water from ditches supplied by Currant Creek and by springs located at the base of the hills about 2 miles east of the town. The underground supply is derived from wells that usually range from 25 to 75 feet in depth. The wells are put down through clay to sand in which water is found under pressure sufficient to cause it to rise almost to the surface, the usual depth to water being 3 to 20 feet. A number of unsuccessful attempts to get flowing wells have been made, the deepest being the railroad well put down near the station. It is 334 feet deep, and water is reported to have risen in it to within a few feet of the surface.

The highland area is underlain chiefly by coarse detritus derived from the adjacent mountains and distributed either as shore deposits in Lake Bonneville or as alluvial accumulations. This higher portion of Goshen Valley is poorly supplied with water, the chief sources being Kimball Creek, a small stream which seldom flows below its mountain course, and Currant Creek, which flows perennially and supplies the lower valley. The discharge of Currant Creek, however, is insufficient for the needs of the upland. A reservoir has been built by damming Currant Creek at the entrance to its canyon course through Long Ridge, and a canal constructed which skirts the upper part of Goshen Valley, but the enterprise has been a failure.

A few springs occur along the eastern base of the Tintic Mountains and some successful attempts have been made there to develop underground water by tunneling. In the upper valley of Kimball Creek there are a number of springs which flow about 100 gallons a minute, and smaller ones occur in several gulches. About 2 miles east of Goshen there is a group of springs at the base of Long Ridge, where water issues through débris and accumulates in several small ponds, the temperature of which is reported to stay at about 70° F. throughout the year. These springs constitute the source of Warm Creek, and their combined flow in November, 1904, was estimated at about 5 second-feet. Water has been developed

[a] Sanchez, A. M., Soil survey of the Provo area, Utah: Bull. Bureau of Soils, U. S. Dept. Agric., 1904.

by tunneling at several localities along the eastern slope of the Tintic Mountains. In the valley of Kimball Creek, in sec. 11, T. 11 S., R. 2 W., there is a tunnel 200 feet long in volcanic rock, which furnishes about 20 gallons a minute, and water sufficient for milling purposes has been developed by drifting into the alluvium and bed rock at the head of Homansville Canyon.[a]

Away from the bordering mountains in the highland portion of Goshen Valley, very little underground water has been obtained, and considering the slight run-off and the small tributary drainage area, not much can be expected. The most favorable locations for sinking wells are along the courses of drainage ways. The most successful are along the course of Kimball Creek, but even there water commonly is not obtained at depths less than 150 feet. A number of dry wells have been sunk in the upland area.

WEST OF UTAH LAKE.

The narrow strip of lowland between the western shore of Utah Lake and the Lake Mountains is very scantily provided with water. The low, narrow mountains catch relatively little precipitation; there are no perennial streams, and the arroyos carry water only for a few days during the year. From the foot of the Bonneville and Provo terraces that extend along the base of the mountains the surface slopes gradually lakeward and is underlain chiefly by coarse-textured deposits.

Along the shore of the lake a number of seep springs occur near water level. They are most abundant from Lehi southward, and there are also a few 2 or 3 miles beyond Pelican Point, where their presence is marked by low, marshy areas, one of which is utilized in the cultivation of a few acres of alfalfa. Near Pelican Point there is a feebly flowing well 90 feet deep, in which water was obtained at a depth of 60 feet; and in a near-by well a feeble flow is also obtained, which is said to come from a depth of 154 feet.

Few if any other attempts have been made to recover underground water in this region. Judging from the wells at Pelican Point one might expect to obtain similar results along the western shore of the lake, but if flows were obtained the water would be at so low an elevation as to make it of little use without pumping. Away from the shore flows can hardly be expected. It may be, however, that limited amounts of water can be found to rise in wells to within pumping distance. Prospecting for shallow wells might be attempted in the arroyos, but because of the limited watershed and precipitation the prospect is not good for obtaining enough underground water for extensive irrigation. Pumping directly from the lake presents attractive possibilities.

WELL DATA.

The writer is indebted for the subjoined list of wells to Messrs. F. D. Pyle and T. F. McDonald. Mr. Pyle worked in Utah Lake Valley and west of Jordan River. Mr. McDonald, whose assistance was obtained through the courtesy of Mr. George W. Snow, engineer of Salt Lake City, collected data east of Jordan River. The yield of flowing wells was commonly measured by means of tables which are here inserted, together with accompanying explanation, because the method aroused popular interest and because the edition of the bulletin in which the tables were published has been exhausted.

METHOD OF MEASUREMENT.[b]

Tables for determining the discharge of water from completely filled vertical and horizontal pipes were prepared a number of years ago by Prof. J. E. Todd, State geologist of South Dakota, who issued a private bulletin describing simple methods of determining quickly, with fair accuracy and with little trouble, the yield of artesian wells. In the following notes the tables and explanations relating to vertical and horizontal pipes are taken from this bulletin. The explanations have been appended by the present writer.

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[a] Smith, G. O., and Tower, G. W., Description of the Tintic district: U. S. Geologic Atlas, special folio 65, U. S. Geol. Survey, 1900.

[b] *Slichter, C. S.:* Water-Sup. and Irr. Paper No. 140, U. S. Geol. Survey, 1905, pp. 37–42.

lining the flow of water discharged through a pipe of uniform diameter all that is necessary
le, still air, and care in taking measurements. Two methods are proposed—one for pipes
vertically, which is particularly applicable before the well is permanently finished, and
zontal discharge, which is the most usual way of finishing a well.
[on page 58] is adapted to wells of moderate size, as well as to large wells. In case the well
iameter than given in the table its discharge can without much difficulty be obtained from
y remembering that, other things being equal, the discharge varies as the square of the
the pipe. If, for example, the pipe is one-half inch in diameter its discharge will be one-
iat of a pipe 1 inch in diameter for a stream of the same height. In a similar manner the
f a pipe 8 inches in diameter can be obtained by multiplying the discharge of the 4-inch

it method the inside diameter of the pipe should first be measured, then the distance from
he pipe to the highest point of the dome of the water above in a strictly vertical direction—
diagram [fig. 5]. Find these distances in table [p. 58, A] and the corresponding figure will
mber of gallons discharged each minute. Wind would not interfere in this case so long as
ements are taken vertically.
od for determining the discharge of horizontal pipes requires a little more care. First meas-
neter of the pipe, as before, then the vertical distance from the center of the opening of the
e convenient point corresponding to it on the side of the pipe, vertically downward 6 inches,
e diagram, then from this point strictly horizontally to the center of the stream, *b* to *e*.

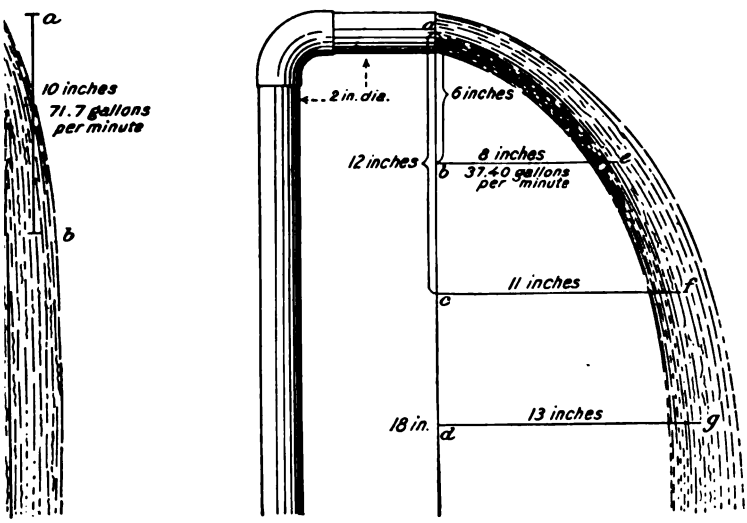

FIG. 5.—Diagram illustrating flow from vertical and horizontal pipes.

lata the flow in gallons per minute can be obtained from table [p. 58, B]. It will readily be
slight error may make much difference in the discharge. Care must be taken to measure
and also to the center of the stream. Because of this difficulty it is desirable to check
rmination by a second. For this purpose columns are given in the tables for corresponding
its 12 inches below the center of the pipe. Of course the discharge from the same pipe should
in the two measurements of the same stream. Wind blowing either with or against the
vitiate results to an indefinite amount. Therefore measurements should be taken while
ll.
fractions occur in the height or horizontal distance of the stream, the number of gallons
ned by apportioning the difference between the readings in the table for the nearest whole
cording to the size of the fraction. For example, if the distance from the top of the pipe
the stream in the first case is 9¼ inches, one-third of the difference between the reading in
9 and 10 inches must be added to the former to give the correct result.
e measures the flow of a well by both methods he may think that the results should agree,
not the case. In the vertical discharge, there being less friction, the flow will be larger; so,
econd method differences will be found according to the length of the horizontal pipe used.
re occasionally at an angle, it is well to know that the second method can be applied to
irst measurement is taken strictly vertically from the center of the opening and the second
t from that point parallel with the axis of the pipe to the center of the stream, as before.
ements can then be read from the table.

Table for determining yield of artesian wells.

[Gallons per minute.]

A.—Flow from vertical pipes.					
Height of jet.	Diameter of pipe in inches.				
	1.	1¼.	1½.	2.	3.
Inches.					
½	3.96	6.2	8.91	15.8	35.6
1	5.60	8.7	12.6	22.4	51.4
2	7.99	12.5	18.0	32.0	71.9
3	9.81	15.3	22.1	39.2	88.3
4	11.33	17.7	25.5	45.3	102.0
5	12.68	19.8	28.5	50.7	113.8
6	13.88	21.7	31.2	55.5	124.9
7	14.96	23.6	33.7	59.8	134.9
8	16.00	25.1	36.0	64.0	144.1
9	17.01	26.6	38.3	68.0	153.1
10	17.93	28.1	40.3	71.6	161.3
11	18.80	29.5	42.3	75.2	169.3
12	19.65	30.7	44.2	78.6	176.9
13	20.46	31.8	45.9	81.8	184.1
14	21.22	33.0	47.6	84.9	190.9
15	21.95	34.2	49.3	87.8	197.5
16	22.67	35.2	50.9	90.7	203.9
17	23.37	36.3	52.5	93.5	210.3
18	24.06	37.5	54.1	96.2	216.5
19	24.72	38.6	55.6	98.9	222.5
20	25.37	39.6	57.0	101.6	228.5
21	26.02	40.6	58.4	104.2	234.3
22	26.66	41.6	59.9	106.7	240.0
23	27.28	42.6	61.4	109.2	245.6
24	27.90	43.5	62.8	111.6	251.1
25	28.49	44.4	64.1	114.0	256.4
26	29.05	45.3	65.3	116.2	261.4
27	29.59	46.1	66.4	118.2	266.1
28	30.08	46.9	67.5	120.3	270.4
29	30.55	47.5	68.5	121.9	274.1
30	30.94	48.2	69.4	123.4	277.6
36	34.1	53.2	76.7	136.3	306.6
48	39.1	61.0	88.0	156.5	352.1
60	43.8	68.4	98.6	175.2	394.3
72	48.2	75.2	108.0	192.9	434.0
84	51.9	81.0	116.8	207.6	467.0
96	55.6	86.7	125.0	222.2	500.0
108	58.9	92.0	132.6	235.9	530.8
120	62.2	98.0	139.9	248.7	559.5
132	65.1	102.6	146.5	260.4	585.9
144	68.0	106.4	153.1	272.2	612.5

B.—Flow from horizontal pipes.				
Horizontal length of jet.	1-inch pipe.		2-inch pipe.	
	6-inch level.	12-inch level.	6-inch level.	12-inch level.
Inches.				
6	7.01	4.95	27.71	19.63
7	8.18	5.77	32.33	22.90
8	9.35	6.60	36.94	26.18
9	10.51	7.42	41.56	29.45
10	11.68	8.25	46.18	32.72
11	12.85	9.08	50.80	35.99
12	14.02	9.91	55.42	39.26
13	15.19	10.73	60.03	42.54
14	16.36	11.56	64.65	45.81
15	17.53	12.38	69.27	49.08
16	18.70	13.21	73.89	52.35
17	19.87	14.04	78.51	55.62
18	21.04	14.86	83.12	58.90
19	22.21	15.69	87.74	62.17
20	23.37	16.51	92.36	65.44
21	24.54	17.34	96.98	68.71
22	25.71	18.17	101.60	71.98
23	26.88	18.99	106.21	75.26
24	28.04	19.82	110.83	78.53
25	29.11	20.64	115.45	81.80
26	30.38	21.47	120.07	85.07
27	31.55	22.29	124.69	88.34
28	32.72	23.12	129.30	91.62
29	33.89	23.95	133.92	94.89
30	35.06	24.77	138.54	98.16
31	36.23	25.59	143.16	101.43
32	37.40	26.42	147.78	104.70
33	38.57	27.25	152.39	107.98
34	39.64	28.08	157.01	111.25
35	40.45	28.64	161.63	114.52
36	41.60	29.46	166.25	117.79
Continue by adding for each inch—				
.....	1.15	0.82	4.62	3.27

NOTE.—To convert results into cubic feet, divide the number of gallons by 7.5, or, more accurately by 7.48.

The flow in pipes of diameters not given in the table can easily be obtained in the following manner:

For ½-inch pipe, multiply discharge of 1-inch pipe by ..... 0.
For ¾-inch pipe, multiply discharge of 1-inch pipe by .....
For 1¼-inch pipe, multiply discharge of 1-inch pipe by 1
For 1½-inch pipe, multiply discharge of 1-inch pipe by 2
For 3-inch pipe, multiply discharge of 2-inch pipe by .....

ipe, multiply discharge of 2-inch pipe by 4.00
pipe, multiply discharge of 2-inch pipe by 5.06
ipe, multiply discharge of 2-inch pipe by 6.25
ipe, multiply discharge of 2-inch pipe by 9.00
ipe, multiply discharge of 2-inch pipe by 16.00

LIST OF TYPICAL WELLS.

Wells in Jordan River and Utah Lake valleys.

t of water above surface indicated by plus +: below surface indicated by minus −.]

owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
.....	T. 1 N., R. 1 E., sec. 31	.....	75	−	.....
ood	do	.....	61	−	.....
son	do	.....	48	−	.....
e	T. 1 N., R. 1 E., sec. 32	.....	35	−	.....
.....	T. 1 N., R. 1 W., sec. 1	.....	18	−14	.....
.....	do	2	312	+	½
.....	T. 1 N., R. 1 W., sec. 3	2	.....	+	5
.....	T. 1 N., R. 1 W., sec. 4	2½	.....	+	1½
.....	T. 1 N., R. 1 W., sec. 5	6	1,002	+	Many.
on	T. 1 N., R. 1 W., sec. 9	2	497	+	6
.....	T. 1 N., R. 1 W., sec. 10	1½	150	+	1½
.....	do	1½	250	+	5
y	T. 1 N., R. 1 W., sec. 11	1½	50	20–50	.....
n	T. 1 N., R. 1 W., sec. 15	2	479	+	.....
nald	T. 1 N., R. 1 W., sec. 17	2	400	+	40
.....	T. 1 N., R. 1 W., sec. 21	2	450	+	30
.....	T. 1 N., R. 1 W., sec. 22	1½	160	+	3–7
.....	do	2	330	+	3
son	T. 1 N., R. 1 W., sec. 23	.....	28	−	.....
.....	do	.....	26	−	.....
er	T. 1 N., R. 1 W., sec. 25	2	60–70	+	.....
.....	do	1½	80	+	2
.....	do	1½	70	−	.....
.....	T. 1 N., R. 1 W., sec. 26	2	400	+	3
.....	do	.....	140	+	1–2
.....	T. 1 N., R. 1 W., sec. 27	2	154	+	1
e	do	2	208	+	.....
.....	T. 1 N., R. 1 W., sec. 34	2	408	+	25
.....	do	1½	250	+	1
.....	do	2	320	+	1½
.....	do	2	350	+	1
.....	T. 1 N., R. 1 W., sec. 35	1½	140	+	.....
.....	do	2	210	+	5
.....	do	2	350	+ 1	15
.....	do	1½	135	+	2
.....	do	2	130	+	3
s	do	1½	68	+	2
.....	T. 1 N., R. 1 W., sec. 36	1½	93	+	15
ock	do	2	95	+	35
.....	do	2	123	+	30
s	do	1½	100	+	25
.....	do	1½	75	+	5–20
;	do	.....	75	−	.....
.....	do	1½	75	−	.....
rs	do	2	96	−	.....
.....	do	2	200	+	9

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
S. A. Gibbs	T. 1 N., R. 1 W., sec. 36	2-3	75-80	+	40
F. Auerbach	T. 1 N., R. 2 W., sec. 25		400		
J. Bond	T. 1 N., R. 2 W., sec. 29		401	+	4
Do	do		465	+	9
Cullen Dairy	T. 1 N, R. 2.W., sec. 35	2		+	
J. Walker	T. 1 S., R. 1 E., sec. 5	1½	80	+	20
P. J. Stone	do		16	− 6	
J. Lunn	do		73	−	
W. J. Kelson	do		45	−	
S. McKay	do		29	−	
Speirs	do		40	−12	
Do	do		12	− 6	
J. E. Wesley	T. 1 S., R. 1 E., sec. 6		75	−	
J. Warburton	do	2	82	+	7
H. S. Sampson	do	2	387	+	8
W. Wheeler	do		10	−	
T. Golightly	do	1½	100	+	
S. K. Hansen	do	2	162	+	6-8
W. N. Sheets	T. 1 S., R. 1 E., sec. 7	2	100	+	30
F. Sproul	do	2	125	+	4
G. Balber	do		170	+	12
F. Rogansky	do		150	+	1
City, about 16 wells	do	2-9	100-600	+35	(?) 600
E. O. Butterfield	do	2	178	+	2-3
J. S. Wooley and others	do		150-200	+	20-50
T. Berg	do	2	155	+	50
Do	do	2	160	+	50
W. Colton	do	2	60	+	6
L. Badger	do	2	165	+	30
J. W. Hicks	do	2	110	+	35
A. Duncan	T. 1 S., R. 1 E., sec. 8	1½	50	− 1	
T. Antisill	do	2	50	+	3
S. M. Alley	do	3	26	−	
S. H. Calder	do	2	246	+	40
S. Sudbury	do	1½	390	+	8
J. R. Miller	do	2	207	+12	30
P. Rosmason	do		41	−	
Mrs. M. Larsen	do		28	− 5- 6	
W. Pickens	do		42	− 7	
A. Ames	T. 1 S., R. 1 E., sec. 9		100	−	
A. S. Martin	T. 1 S., R. 1 E., sec. 10		130	−	
J. A. Shelter	T. 1 S., R. 1 E., sec. 15		85	−65	
L. Hunt	do		51	−30-50	
A. Hord	T. 1 S., R. 1 E., sec. 16		54	−	
A. Martin	do		56	−46	
H. E. Thorp	do		18	−	
J. S. Southern	T. 1 S., R. 1 E., sec. 17		32	−	
A. Buggs	do		22	− 4-16	
J. E. Nailor	do		20	− 5-14	
T. Y. Taylor	do	2	100	−	
(a)	do	2	200	+	6
W. H. Miller	do	2	335	+	50
W. H. Burnett	do		15	− 3-11	
M. C. Sandford	do		33	− 3	

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
.....	T. 1 S. R. 1 E., sec. 17	.....	33	−28	.....
)	do	.....	10	−	.....
.....	do	.....	14	−	.....
.....	do	.....	48	−43	.....
.....	T. 1 S., R. 1 E., sec. 18	2	325	.....	4-5
.....	do	2	300	+	30-40
s.....	do	2	100	+	30
.....	do	2	164	+	10
lbury.....	do	.....	160	+	18
es.....	do	.....	20	−	.....
.....	do	2	72-82	+	30-40
an.....	do	2	500	+	5
.....	do	2	600	+	12-14
o.....	do	2	636	+	(?) 150
.....	do	2	150	+	10
.....	do	2	40	+	18
.....	do	2	325-330	+	30-40
.....	do	.....	501	+	80
.....	do	3	382	+	(?) 100
.....	do	.....	17	−	.....
sen.....	do	2	250-300	+	1-13
.....	do	2	322	+	55
)	do	.....	560	+	20-30
tezhoh....	do	3	40	−	.....
.....	do	2	298	+	10-12
an.....	do	2	100	+	5-6
.....	do	1½	50	+	8
.....	do	.....	160-170	−	.....
.....	T. 1 S., R. 1 E., sec. 19	3	323	.....	.....
n.....	do	2	296	+	50-60
on.....	do	2	285	+	60
.....	do	2	150	+	25
.....	do	2	437	+	10-30
.....	do	.....	100	.....	.....
.....	do	2	94	+	17-20
.....	do	2	60	+	1
.....	do	2	176	+	18
g.....	do	2	180	+	20-25
g.....	do	.....	90	+	20-25
or.....	do	2	181	+	(?) 100
all.....	do	1¾	84	+	10
.....	do	2	212	+	1
er.....	do	2	75	+	.....
.....	do	2	240	+	.....
.....	do	.....	.....	+	30
)	do	.....	150	.....	40
t.....	do	2	150-160	.....	46
.....	T. 1 S., R. 1 E., sec. 20	.....	23	−20	.....
.....	do	.....	26	.....	.....
r.....	do	3	65	.....	.....
.....	do	.....	40	+	5-6
s.....	do	.....	162	+	½
n.....	do	2	156	+	28
on.....	do	.....	21	−14-15	.....

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
C. Hansen	T. 1 S., R. 1 E., sec. 20		22	− 18	
P. R. Ryon	do		158	+	80
G. Cusiman	do		18	− 15	
W. C. Smoot	do		22	− 19	
J. Neff	T. 1 S., R. 1 E., sec. 26		23	−	
C. Banford	do		100	−	
J. Fisher	T. 1 S., R. 1 E., sec. 27		33	− 20	
J. Young	do		184	−104	
F. Ereickson	T. 1 S., R. 1 E., sec. 28		27	− 25	
J. Childs	T. 1 S., R. 1 E., sec. 29		55	−	
W. M. Tillman	do		68	−	
F. Degenhart	do	2	68	− 37	
J. P. Cahoon	do		26	−	
W. S. Timmons	do	2	194	+	9
J. T. Guest	do	2	187	−	
R. Pike	do		40	− 34	
J. Madsen	do		260	− 16	
J. S. Gustavensen	do	2	190	+	2
H. Hizzard	do		200	+	2
Mrs. C. Green	do		184	−	
Do	do		215	+	11
S. F. Evans	do	2	208	−	
O. Reece	do		209	+	30
Do	do		245	+	30
Do	do		245	+	13
L. Stutts	do	2	141–143	+	40
S. Hicks	do	2	100	+	30
E. E. Keithley	do	3	120	+	(?) 100
H. Burnett	do		202	+	27
Do	do		24	−	
W. J. Miller	do	2	200	+	20
G. Fairbourne	do	2	128	+	20
J. Tremayave	T. 1 S., R. 1 E., sec. 30	2	251	+	20
G. Taylor	do		104	+	
W. Chantron	do	2	235	+	30
J. J. Spencer	do	2	240	+	17
M. M. Listen	do	2	110	+	5
J. Cobert	do		216	+	24
School	do	2	218	+	12
G. Calder	do	2	130	+	45
R. Norman	do	1½	100	+ 6	
Mrs. A. S. Berg	do	2		+	25
A. Johansen	do	2	175	+	5
(a)	do	2		+	30
Murray Live Stock Co.	do	2		+	40–60
M. Knudsen	do		300	+	20
L. White	do		185–230	+	60
E. J. Williams	do	2	82–83	+	25
Do	do	2	50	+	1
C. Halford	do	1¼	160	+	10
A. M. Rymarson	T. 1 S., R. 1 E., sec. 31	2	202	+	35
Do	do	2	72	+	6
L. Parks	do	2	237		
J. Hulse	do	2	160	+	20

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

ner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
.....	T. 1 S., R. 1 E., sec. 31	2	130	+	20
.....	do	2	255	+	30
.....	do	.....	83	+	.....
.....	do	2	209	+	40
.....	do	.....	211	+	20
.....	do	2	203	+	12
.....	do	.....	150	+	(?) 110
.....	do	.....	90	+	.....
.....	do	.....	130	+	15
.....	do	.....	80	+	½
.....	do	2	244	+	8
.....	T. 1 S., R. 1 E., sec. 32	2	210	+	28
.....	do	.....	70	+	35
.....	do	.....	196	+	6
.....	do	.....	235	+	20
.....	do	.....	160	+	.....
.....	do	.....	160	+	1-12
.....	do	.....	165	+	.....
.....	do	2	193	+	1
.....	do	2	55	+	
.....	do	.....	33	− 24	.....
.....	do	.....	25	− 22	.....
.....	do	.....	54 56	−	.....
.....	do	.....	70-150	−	.....
.....	T. 1 S., R. 1 E., sec. 33	.....	25	.	.....
.....	do	3	520	− 419	.....
.....	do	3	350	+	25
.....	T. 1 S., R. 1 W., sec. 1	1½	317	+	1
.....	do	2	300	+	20
dsen.....	do	1½	202	+	2
	T. 1 S., R. 1 W., sec. 2	2	120	+	.....
.....	do	3	1,100	+	30
.....	do	2	114	+	1½
a.....	do	2	318	+	6
.....	do	2	335	+	4
.....	do	1	95	+	2½
sy.....	do	4	1,072	+ 30	80
.....	T. 1 S., R. 1 W., sec. 3	2½	381	+	16
.....	T. 1 S., R. 1 W., sec. 4	2	280	+	3
.....	T. 1 S., R. 1 W., sec. 5	2	360	+ 4½	7
.....	do	2	385	+	6
.....	T. 1 S., R. 1 W., sec. 7	1½	154	−	.....
.....	do	2	405	+	10
.....	do	1½	154	+	.....
.....	T. 1 S., R. 1 W., sec. 8	2	325	+ 1	1
ol.....	T. 1 S., R. 1 W., sec. 9	2	320	+	5-6
.....	do	1½	98	+ 1	1
.....	T. 1 S., R. 1 W., sec. 10	3	624	+	30-40
.....	T. 1 S., R. 1 W., sec. 11	2	377	+	9
1.....	do	2	130	+	20-30
.....	do	.....	165	+	6-7
.....	do	2	.....	+	25
.....	do	2	367-387	+	5-6
.....	do	2	456	+	60-70

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute
		Inches.	*Feet.*	*Feet.*	*Gallons*
E. Kidd	T. 1 S., R. 1 W., sec. 12	2	475	+	
A. H. White	do		300	+	
J. Anderson	T. 1 S., R. 1 W., sec. 13		400		
J. H. Shaffer	do		18		
Lambert Paper Co	do	2	177		
R. Cutler	do	2	315	+	
J. Gabbot	do	2	380	+	
(a)	do	2	275	+	
J. S. McCallan	T. 1 S., R. 1 W., sec. 14		355	+	
J. G. Gumman	T. 1 S., R. 1 W., sec. 16	2	330	+	
Schoolhouse	T. 1 S., R. 1 W., sec. 17	2	400	+	
S. C. Sudbury	T. 1 S., R. 1 W., sec. 18	2	412	+12	
L. S. Hansen	T. 1 S., R. 1 W., sec. 21	1½		+	
N. Hansen	T. 1 S., R. 1 W., sec. 24		145	−	
S. Sorensen	do	2	385	−	
Gilchrist	T. 1 S., R. 1 W., sec. 25	1½	130	−	
Rockhill	do	2	120	+	
P. Austin	do	2	145	−	
G. H. Walton	do	2	350	+30	
B. Harmon	T. 1 S., R. 1 W., sec. 26	2	350	+30	
(a)	T. 1 S., R. 1 W., sec. 28	1½	290	−	
Murray	do			+	
C. J. Lambert	T. 1 S., R. 1 W., sec. 29		182	+	
L. Burden	do		70		
N. P. Peterson	T. 1 S., R. 1 W., sec. 31		50	−30	
J. C. Poulton	do		60	−51	
(a)	T. 1 S., R. 1 W., sec. 32	1½	290	−	
T. R. Jones	T. 1 S., R. 1 W., sec. 35	2	345	−	
Do	do	1½	75	−	
(a)	T. 1 S., R. 1 W., sec. 36	1½	140	+	
J. P. Anderson	T. 1 S., R. 2 W., sec. 1		160	−	
(a)	do	2	260	+	
(a)	T. 1 S., R. 2 W., sec. 14	2	150	+	
Wolstenholm	T. 1 S., R. 2 W., sec. 21	1½	30	+	
Spencer	do		68	+	
Oslen	do	3	150	+	
Butterworth	do	1½	175	+	
T. West	T. 1 S., R. 2 W., sec. 22	2	40	+	
N. T. West	do	1½	40	+ 3	
J. Michaels	T. 1 S., R. 2 W., sec. 23	1½	90	+ 6	
J. Hayhoe	T. 1 S., R. 2 W., sec. 26	1½	177	+	
Goodwin	T. 1 S., R. 2 W., sec. 27		27	−21	
A. Cockerill	T. 1 S., R. 2 W., sec. 29	1½	118	−14	
Speirs	T. 1 S., R. 2 W., sec. 33		84	−	
J. Kersey	T. 1 S., R. 2 W., sec. 34	42	166	−66	
Inland Crystal Salt Co.	T. 1 S., R. 3 W., sec. 2	4	720	+ 9	
Salt Lake and Los Angeles Rwy. Co.	do		330	+12	
P. J. Reid	T. 1 S., R. 3 W., sec. 24		134	+	
J. Bertock	do	1½	73	+	
J. Neilson	T. 2 S., R. 1 E., sec. 3	4	540	−	
G. Coleman	do		62	−	
T. Newman	do		65	−	
T. Gundesser, jr.	T. 2 S., R. 1 E., sec. 4		18	−	D

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
›ank	T. 2 S., R. 1 E., sec. 4	.....	104	+	46
.....	do	.....	102	+	25
ıd	do	2	76	+	15
.....	do	2	78	+	24
.....	do	2	99	+	4
.....	do	3	232	−	.....
an	do	2	225	−	.....
.....	do	2	70-100	+	20-34
.....	do	2	65	+	4
.....	do	.....	335	+	20
.....	do	3	122	−70	.....
.....	T. 2 S., R. 1 E., sec. 5	.....	200	+	1½
.....	do	2	108	+	25
ıs	do	2	180	+	3-5
ark	do	.....	90	+	2
.....	do	.....	384	+	5
.....	T. 2 S., R. 1 E., sec. 6	2	100	+	10
.....	do	2	194	+	10
.....	do	2	90	+	32
.....	do	2	255	+	28
.....	do	2	80	+	4
.....	do	2	255	+	40
›nsen	do	2	210	+	20
.....	T. 2 S., R. 1 E., sec. 7	2	150	+	40
.....	do	3	115	+	1
kson	do	2	80	+	30
ıs	do	2	315	+	15
ns	do	2	100	+	4
.....	do	.....	190	+	10
.....	do	2	189	+	38
.....	do	.....	230	+	.....
ski	do	.....	300	+	2
.....	T. 2 S., R. 1 E., sec. 8	.....	215	+	10
.....	do	.....	230	+	7
.....	do	5	85	+	(?)160
.....	do	2	82	+	22
.....	do	.....	80	+	20
.....	do	.....	172	+	10
.....	do	1½	80	+	20
tchery	do	4	.....	+	(?)130
.....	do	4	.....	+	(?)100
.....	do	2	80	+	40
.....	do	.....	310	+	17
.....	do	2	.....	+	30
ı	T. 2 S., R. 1 E., sec. 9	.....	120	+	6
d	do	2	148	+	18
.....	do	2	96	+	20
.....	do	2	275-250	+	.....
.....	do	3	60	+	(?)100
s	do	2	100-103	+	43
.....	do	.....	92-96	+	25
.....	do	1½	100	+	20
.....	do	2	.....	+	30
ı	T. 2 S., R. 1 E., sec. 10	.....	14	−	(a)

[a] Dry 9 months in year.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yi mi
		Inches.	*Feet.*	*Feet.*	Ga
A. Olander	T. 2 S., R. 1 E., sec. 15		18	− 16	.....
J. Spillet	do		15	− 10-11	.....
J. Smith	T. 2 S., R. 1 E., sec. 16		20	− 4-17	.....
J. Hemmert	do	2	78	− 40	.....
S. Neilson	do		18-20	− 8-10	.....
S. F. Smith	do		20	− 10	.....
A. L. Hansen	do		22	− 11	.....
J. W. McHenry	do		18	− 12	.....
J. Hobbs	do		113	− 9	.....
J. Furgeson	do		60	+	
I. Furgeson	do		60	+	.....
O. Headman	do		92	−	.....
J. Brighouse	T. 2 S., R. 1 E., sec. 17	1½	58	+ 16	
H. V. Ballard	do	2	83	+ 8	
G. Peterson	do		14	− 9	.....
District school	do		250	− 12	.....
R. Brown	do		40	+ 8	.....
R. M. Ballard	do	1½	46	+	
Mrs. Shumann	do	2	50-60	+	
H. E. Howe	do		60	+	
D. A. Rauser	do		45	+	
J. T. Erickson	do	2	175	+	
F. C. Howe	do	2	90	+	
Do	do	2	190	+	
J. B. Thompson	do	1½	75	+	
Do	do	2	80	+	
E. Taylor	T. 2 S., R. 1 E., sec. 18		125	−117	.....
E. Gillen	do	2	20-30	−	.....
H. Berger	do	3	90	− 10	.....
C. Turner	do		70-80	− 4-13	.....
H. Chambers	do	2	200	− 10	.....
J. Jones	do	2	22	−	.....
J. H. Wheeler	do	2	75-100	+	
South Cottonwood Ward.	do	2	75-100	+	
Do	do	3	110	+	
Mrs. J. Clark	do		18	− 4	.....
M. Sibbs	T. 2 S., R. 1 E., sec. 19	2	50	−	.....
N. Nelson	do		22	− 8	.....
C. Atkinson	T. 2 S., R. 1 E., sec. 20		10	−	.....
H. Wheeler	do		12	−	.....
C. B. Walder	do		22	−	.....
C. J. Wright	do		10	−	.....
W. Barrett	T. 2 S., R. 1 E., sec. 21		16	−	.....
J. E. Brown	do		13	−	.....
H. C. L. Russell	do		50	− 30	.....
J. W. Fawlke	T. 2 S., R. 1 E., sec. 22		6	−	.....
A. Fawlke	do		12	−	.....
S. Jones	T. 2 S., R. 1 E., sec. 26		80	− 55	.....
A. D. Brown	T. 2 S., R. 1 E., sec. 27		96	− 93	.....
(a)	T. 2 S., R. 1 E., sec. 28		125	−	.....
W. Baggas	T. 2 S., R. 1 E., sec. 29		18	−	.....
D. M. Griffin	do		22	−	.....
J. A. Wagstaff	do		35	−	.....

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

wner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
.....	T. 2 S., R. 1 E., sec. 29	.....	30	− 26–27	.....
.....	T. 2 S., R. 1 E., sec. 30	.....	35	.....	.....
.....	do	2	200	− 7–10	.....
.....	do	2	22	−	.....
.....	T. 2 S., R. 1 E., sec. 31	.....	40–50	− 25–34	.....
.....	do	.....	29–30	− 26	.....
en.	do	.....	51	− 41	.....
1	do	.....	90	− 60	.....
.....	do	.....	53	−	.....
.....	do	.....	26	−	.....
.....	do	.....	15	−	.....
.....	T. 2 S., R. 1 E., sec. 32	.....	100	− 75	.....
.....	do	.....	14	−	.....
.....	do	.....	200	−200	.....
.....	T. 2 S., R. 1 E., sec. 33	.....	22	−	(a)
.....	T. 2 S., R. 1 E., sec. 34	.....	40	−	.....
n	T. 2 S., R. 1 E., sec. 35	.....	50	−	Dry.
.....	do	.....	40	− 26	.....
.....	T. 2 S., R. 1 W., sec. 1	2	40	+	20–35
.....	do	.....	100	+	40
.....	do	.....	287	+	2
.....	do	2	140	+	22
.....	do	2	90	+	25
.....	do	.....	65	+	8
.....	do	.....	280	−	.....
.....	T. 2 S., R. 1 W., sec. 2	.....	372	− 18	.....
.....	do	.....	240	+	6
.....	T. 2 S., R. 1 W., sec. 3	.....	212	− 10	.....
.....	do	.....	260	− 25	.....
	T. 2 S., R. 1 W., sec. 6	.....	56	−	.....
.....	T. 2 S., R. 1 W., sec. 8	3	157	− 37	.....
.....	do	.....	120	− 60	.....
.....	do	3	150	− 50	.....
.....	T. 2 S., R. 1 W., sec. 9	3	110	−	.....
.....	T. 2 S., R. 1 W., sec. 10	3	141	− 40	.....
.....	T. 2 S., R. 1 W., sec. 11	3	315	+	35
.....	do	.....	222	− 15	.....
.....	do	2	323	+	5
.....	do	3	85	−	.....
.....	T. 2 S., R. 1 W., sec. 12	3	77	− 36	.....
ing Co	do	.....	100	+	40
.....	do	2	350	+	15
.....	do	2	249	+	20
.....	do	2	117	+	20
n	do	2	345	− 8	.....
.....	T. 2 S., R. 1 W., sec. 13	3	180	−	.....
mmer	do	3	60	− 30	.....
	do	.....	9½	− 6½	.....
.....	do	2	50	− 10	.....
.....	T. 2 S., R. 1 W., sec. 14	3	80	− 40	.....
.....	do	.....	22	− 12	.....
st	do	2½	175	− 6	.....
.....	do	2	180	+	12

[a] *Dry in winter.*

[b] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per min
		Inches.	*Feet.*	*Feet.*	*Gal*
J. Anderson	T. 2 S., R. 1 W., sec. 15		117	− 50	
School	do		165	− 50	
W. Diamond	T. 2 S., R. 1 W., sec. 22	3	345	−110	
M. Parker	do		225	− 40	
M. Hansen	do		140	− 90	
(a)	T. 2 S., R. 1 W., sec. 23		185	− 24	
C. Erickson	T. 2 S., R. 1 W., sec. 24		30	− 12	
E. Bateman	T. 2 S., R. 1 W., sec. 25	3	251	−	
(a)	do		20	− 16	
Bingham School	do	3	325	− 60	
J. B. Wright	T. 2 S., R. 1 W., sec. 26	3	230	− 40	
E. Gardner	do		180	− 20	
(a)	T. 2 S., R. 1 W., sec. 27		100	− 30	
Cooper	do	3	254	+	
W. D. Runsal	do		137	− 33	
A. L. Cooley	T. 2 S., R. 1 W., sec. 30		28	−	
Olsen	T. 2 S., R. 1 W., sec. 33		178	− 20-30	
Cannon Farm	T. 2 S., R. 1 W., sec. 34	3	1,000	− 30	
R. Egbert	do	6	52	− 24	
P. T. Rundquist	do	3	80	− 18	
M. Pusler	T. 2 S., R. 1 W., sec. 35	3	217	−	
J. Peterson	do		127	− 53	
N. L. Gardner	do	3	309	− 25	
G. Hunt	T. 2 S., R. 1 W., sec. 36		21	− 17	
S. M. Wilmore	do	3	225	− 8	
N. Nelson	do		190	− 75	
(a)	do		50	−	
P. Jansen	do		30	− 17	
P. J. Wolff	T. 2 S., R. 2 W., sec. 11		174		
Olsen	T. 2 S., R. 2 W., sec. 27	3	150	+	
H. Brown	T. 3 S., R. 1 E., sec. 2		38-40	−	
W. L. Bateman	T. 3 S., R. 1 E., sec. 5		14-16	− 6	
E. Johnson	T. 3 S., R. 1 E., sec. 6		40	−	
C. Peterson	do		28	− 25	
A. Yelter	T. 3 S., R. 1 E., sec. 7		75	− 70	
H. P. Hansen	T. 3 S., R. 1 E., sec. 8		56	− 45-52	
P. Anderson	T. 3 S., R. 1 E., sec. 9		125		
R. Despain	T. 3 S., R. 1 E., sec. 11		16		
C. Williams	T. 3 S., R. 1 E., sec. 17		30	− 28	
F. Olsen	T. 3 S., R. 1 E., sec. 18		40	− 24	
P. A. Yastrop	T. 3 S., R. 1 E., sec. 19		80	−	
J. P. Jenson	do		95	−	
E. N. Fish	T. 3 S., R. 1 E., sec. 21		34		
J. L. Johnson	T. 3 S., R. 1 E., sec. 22		65	−	
J. W. Smith	T. 3 S., R. 1 E., sec. 28		10	−	
H. Pearson	T. 3 S., R. 1 E., sec. 29		18	−	
J. Tarry	do		18-20	−	
N. Brown	do		16	−	
J. R. Stocking	do		42	−	
A. J. Wilson	T. 3 S., R. 1 E., sec. 32	4	70	− 62	
J. R. Allen	do		24	− 18	
J. Ennis	do		41	− 35	
J. Boulter	T. 3 S., R. 1 E., sec. 33		22	− 17	
F. B. Ladler	do		66		

[a] Owner's name unknown.

[b] Dry in winter.

Wells in Jordan River and Utah Lake valleys—Continued.

wner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
.....	T. 3 S., R. 1 W., sec. 1.....	2	323	+	5
.....	.....do.....	3	200	−40	.....
.....	.....do.....	.....	30	.....	.....
.....	.....do.....	3	412	−58	.....
.....	T. 3 S., R. 1 W., sec. 2.....	3	236	−43	.....
.....	T. 3 S., R. 1 W., sec. 3.....	.....	250	−20	.....
.....	.....do.....	.....	212	−40	.....
.....	T. 3 S., R. 1 W., sec. 12.....	3	137	−	.....
.....	T. 3 S., R. 1 W., sec. 13.....	3	156	−45	.....
.....	T. 3 S., R. 1 W., sec. 15.....	3	255	−85	.....
.....	.....do.....	.....	500	−75	.....
.....	T. 3 S., R. 1 W., sec. 23.....	2	50	.....	12–15
gton.....	.....do.....	1¼	28	.....	12–15
.....	T. 3 S., R. 1 W., sec. 24.....	.....	30	−12	.....
.....	.....do.....	3	127	−	.....
.....	.....do.....	.....	28	−	.....
.....	T. 3 S., R. 1 W., sec. 25.....	.....	15	− 4	.....
.....	.....do.....	3	133	−40	.....
.....	T. 3 S., R. 1 W., sec. 26.....	2	90	+12	.....
.....	T. 3 S., R. 1 W., sec. 27.....	3	225	−60	.....
.....	T. 3 S., R. 3 W., sec. 26.....	3	102	−	.....
.....	T. 4 S., R. 1 E., sec. 5.....	2	400	+	3
.....	.....do.....	.....	40	−	.....
.....	.....do.....	2	125	+	.....
.....	T. 4 S., R. 1 E., sec. 6.....	.....	20	−10	.....
.....	T. 4 S., R. 1 E., sec. 32.....	.....	41	−35	.....
.....	.....do.....	.....	15	−	.....
d.....	T. 4 S., R. 1 E., sec. 33.....	.....	42	−	.....
.....	.....do.....	.....	21	− 8	.....
.....	T. 4 S., R. 1 E., sec. 24.....	.....	25–80	.....	.....
.....	T. 4 S., R. 1 W., sec. 3.....	.....	30	.....	.....
.....	.....do.....	3	99½	−40	.....
.....	.....do.....	3	130	−40	.....
.....	T. 5 S., R. 1 E., sec. 4.....	.....	32	−20	.....
.....	T. 5 S., R. 1 E., sec. 5.....	.....	15–50	−10–40	.....
.....	T. 5 S., R. 1 E., sec. 7.....	2	134	+25	.....
ge.....	.....do.....	1¼	125	−	.....
.....	.....do.....	1½	125	−	.....
.....	.....do.....	1¼	90–100	+	12
.....	.....do.....	2	193	−	.....
n.....	.....do.....	2	90–100	+	55
.....	T. 5 S., R. 1 E., sec. 8.....	.....	12	−	.....
.....	.....do.....	1½	145	− 8–10	.....
.....	.....do.....	1¼	75	−	.....
.....	.....do.....	.....	12	−	.....
.....	.....do.....	.....	20	−	.....
.....	T. 5 S., R. 1 E., sec. 9.....	2	145	−22	.....
	.....do.....	2	130	+	5
.....	.....do.....	1¼	135	−	.....
	.....do.....	2	300	+	4
os Ange-lt Lake	.....do.....	2	330	+	23
.....	.....do.....	1¼	330	+	35
.....	.....do.....	3	300	− 8	.....
.....	.....do.....	1½	140	−	.....

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
W. Hunger	T. 5 S., R. 1 E., sec. 9	2	145	− 2	(?)25
Rhodes	do	1½	140	+	9
Wing	do	1½	158	−	
Anderson	do	2	132	+	20
Gilchrist	do	1¼	130	− 6	
Barney	T. 5 S., R. 1 E., sec. 10	1¼	145	+	20
D. Wagstaff	T. 5 S., R. 1 E., sec. 14	2	270	−	
A. L. Thornton	do	2	201	+	2
American Fork, city well.	do	3	460	−25	
A. Green	T. 5 S., R. 1 E., sec. 15		160	+	
J. B. Greene	do	2	160	+	40
J. Stewart	T. 5 S., R. 1 E., sec. 16	2	140	+	
Broadbent	do	2	150	+	10
A. K. Thornton	do	3	543	− 4½	
T. J. Chipman	do	2½	263	− 2	
J. Peters	do	6	33	−	
A. Field	do	1½	162	+	5
Mrs. K. Fox	do	2	130	+	10
(a)	do	2	90	+	10
(a)	do	2		+	15
(a)	do	2	90	+	20
(a)	T. 5 S., R. 1 E., sec. 17		147		
O. Ellington	do	1¼	150	+	
E. A. Bushman	do	2	350	−	
Anderson	do	2	132	+	20
D. J. Thurman	do	2	150	+	10
J. Donaldson	do	2	143	+	20
J. Stewart	do	2	140	+	
P. Jacobs	do	1¼	140	+	5
J. Woodhouse	do	1½	164	−	
M. Evans	do	2	200	+ 3	(?)100
Rio Grande Western Rwy.	do	3	165	+30	30
G. Webb	T. 5 S., R. 1 E., sec. 18	2	195	+ 3	40
S. R. Taylor	do	2	156	+10	
W. H. Chipman	T. 5 S., R. 1 E., sec. 23	2	147	+	(?)150
Do	T. 5 S., R. 2 E., sec. 11	2	135	+46	(?)200
B. Willis	T. 5 S., R. 2 E., sec. 18	2	160	+	
M. Evans	do	2		+	30
(a)	T. 5 S., R. 2 E., sec. 19	2		+	20
J. D. Godey	do	2	290	+	
S. E. Davis	do	2	150	+	80
W. Howe	T. 5 S., R. 2 E., sec. 20	2	200	+	20
Clarke	do	2	40	+	
Lott	T. 5 S., R. 2 E., sec. 21	2	100	+	60
(a)	T. 5 S., R. 2 E., sec. 23	2	264	+	10
Elgin creamery	do	3		+	
A. F. Adams	do	3	280	+	15
American Fork City	do	3	280	+	
W. Anderson	T. 5 S., R. 2 E., sec. 25	1¼		+	10
W. D. West	T. 5 S., R. 2 E., sec. 29	2	64	+	15
Do	do	2	70	+	
(a)	do	2	74	+	35-50
Wadley	do	2	200	−33	
W. D. West	do	2	70	+18	

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

ner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
.....	T. 5 S., R. 2 E., sec. 29	2	115	+20	45
	T. 5 S., R. 2 E., sec. 32	2	150	+	.....
	.....do	2	80	+	40
.....	.....do	2	160	+	90
.....	.....do	2	150	+15	.....
.....	T. 5 S., R. 2 E., sec. 35	2	90	+	25
.....	.....do	.....	100	+	.....
.....	T. 5 S., R. 1 W., sec. 1	.....	100	+	80
.....	T. 5 S., R. 1 W., sec. 12	2	100	+ 7 ins.	.....
(about	.....do	2-6	100	+30	(?)2,000
.....	T. 5 S., R. 1 W., sec. 13	2	258	+	32
	.....do	2	112	+	.....
.....	T. 5 S., R. 1 W., sec. 24	2	160	+14	.....
.....	T. 6 S., R. 2 E., sec. 5	2	210	+	.....
.....	.....do	2	130	+	.....
.....	T. 6 S., R. 2 E., sec. 7	3	110	+	(?)260
.....	.....do	2	112	+11	.....
.....	T. 6 S., R. 2 E., sec. 8	2	110	+	(?)100
.....	T. 6 S., R. 2 E., sec. 10	.....	72	−67	.....
.....	T. 6 S., R. 2 E., sec. 14	.....	110	−	.....
'o.....	.....do	3	250	−80	.....
.....	.....do	.....	60	−40-55	.....
.....	.....do	2	300	−	.....
.....	T. 6 S., R. 2 E., sec. 15	.....	72	−62	.....
/.....	T. 6 S., R. 2 E., sec. 17	2-3	120-140	+ 1-10	(?)1-200
.....	.....do	2	100	+	30
.....	T. 6 S., R. 2 E., sec. 18	3	100	+12	.....
.....	.....do	2	110	+	(?)100
.....	T. 6 S., R. 2 E., sec. 21	2	104	+	25
.....	T. 6 S., R. 2 E., sec. 23	.....	52	−50	.....
.....	T. 6 S., R. 2 E., sec. 24	.....	40	−36	.....
.....	T. 6 S., R. 2 E., sec. 26	48	65	−60	.....
.....	T. 6 S., R. 2 E., sec. 28	2	110	+	10
.....	.....do	1½	98	+	10
.....	T. 6 S., R. 2 E., sec. 34	.....	125	+	.....
.....	.....do	.....	110	+	.....
.....	.....do	1½	130	+	.....
.....	T. 6 S., R. 2 E., sec. 35	2	210	−25	.....
.....	.....do	.....	24	−	.....
.....	T. 6 S., R. 3 E., sec. 31	.....	50	−40-45	.....
.....	T. 7 S., R. 2 E., sec. 1	2	217	+	48
.....	.....do	2	145	+	6
.....	T. 7 S., R. 2 E., sec. 2	2	145	+	.....
.....	.....do	2	145	+	8
.....	.....do	2½	150	+10	.....
.....	.....do	2	130	+	85
.....	T. 7 S., R. 2 E., sec. 3	1½	135	+	25
.....	.....do	.....	110	+	.....
.....	.....do	2	128	+	.....
.....	.....do	.....	35	−	.....
.....	T. 7 S., R. 2 E., sec. 4	.....	50	−	.....
.....	T. 7 S., R. 2 E., sec. 9	2	342	+	80
.....	T. 7 S., R. 2 E., sec. 10	.....	12	− 4	.....
.....	T. 7 S., R. 2 E., sec. 11	2	184	+	82

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield minut
		Inches.	*Feet.*	*Feet.*	*Gallo*
Westron	T. 7 S., R. 2 E., sec. 11	2	180	+	.....
W. B. Johnson	do	1½	160	+	
M. Christensen	do	2	168–178	+	
B. Johnson	do	2	150	+	
W. Carter	do	2	170	+	
Rio Grande Western Rwy.	T. 7 S., R. 2 E., sec. 12	3	175	+	(
San Pedro, Los Angeles and Salt Lake R. R.	do	3	192	+35	(
W. R. Pike	do	1½	248	+12	
Do	do	1¼	198	.....	
W. J. Woodhead	do	2	168	+	
H. Manney	do	.....	168	+	
Hospital	do	.....	180	+	.....
W. Scott	do	2	150	+	
S. W. Sharp	do	2	197	+	
Farris Bros	do	.....	185	+	
S. Copp	do	2	175	+	
Watkins & Taylor	do	.....	300	+	
(a)	T. 7 S., R. 2 E., sec. 14	1½	145	+	
A. B. Johnson	do	.....	170	.....	.....
G. T. Peay	T. 7 S., R. 2 E., sec. 16	2	137	+ 5	
A. W. Hanrer	T. 7 S., R. 3 E., sec. 6	2	140	+ 2	
T. E. Thurman	do	1½	333	+20	
J. Anderson	T. 7 S., R. 3 E., sec. 8	2	150	+20	
Utah Co. Infirmary	T. 7 S., R. 3 E., sec. 17	3	270	+	
H. M. Dougal	T. 7 S., R. 3 E., sec. 29	2	180	+10	
Do	T. 7 S., R. 3 E., sec. 30	2	220	+ 4	
Clubhouse	do	1½	299	+	
Do	do	2	128	+	
P. Boyer	T. 7 S., R. 3 E., sec. 31	2	150	+	
Rio Grande Western Rwy.	T. 7 S., R. 3 E., sec. 32	3	220	+30	
(a)	do	1½	232	+	
J. B. Stevenson	T. 7 S., R. 3 E., sec. 33	1½	101	+	
D. Wheeler	do	2	131	+	
D. Clark	do	2	240	+	.....
A. Cox	do	3	230	+18	
W. Findley	do	2	135	+	
(a)	do	2	115	+	
A. Oakley	do	2	128	+	
(a)	do	2	105	+	
J. McCurdey	do	.....	22	–	.....
(a)	do	1½	120	+	
T. L. Mendenhall	do	2	245	+	
S. Fuller	do	.....	25	–	.....
M. Dougal	do	1½	230	+	
E. P. Brinton	do	2	130	+	
McKenzie	do	1½	132	+	
Daley	do	1½	145	+	
F. W. Phillips	do	2	217	+	
(a)	do	2	138	+	
W. Brookes	T. 8 S., R. 1 E., sec. 11	1¼	160	.....	
(a)	do	1¼	100	– 4	.....
(a)	T. 8 S., R. 1 E., sec. 24	1½	.....	+	

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

ıer.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
.....	T. 8 S., R. 2 E., sec. 2.....	2	438	+	25
.....	T. 8 S., R. 2 E., sec. 4.....	2	366	+	72
.....	.....do.....	1½	380	+	20
.....	.....do.....	2	175	+10	20
	.....do.....	1¼	112	+	10
	.....do.....	2	175	+	12
.....	T. 8 S., R. 2 E., sec. 7.....	2	225	+	.....
.....	T. 8 S., R. 2 E., sec. 8.....	1½	400	+12	8-25
.....	.....do.....	2	230	+10	35
.....	.....do.....	2	350	+	8
.....	T. 8 S., R. 2 E., sec. 9.....	2	400	+	.....
.....	.....do.....	2	390	+10	40
.....	T. 8 S., R. 2 E., sec. 10.....	1½	142	+	.....
.....	.....do.....	3	430	+	15
.....	T. 8 S., R. 2 E., sec. 12.....	2	280	+	10
.....	.....do.....	2	260	+	5
.....	T. 8 S., R. 2 E., sec. 13.....	2	220	− 4	.....
Ange- Lake					
.....	.....do.....	2	405	+	36
.....	T. 8 S., R. 2 E., sec. 14.....	2	380	+	16
.....	.....do.....	3	423	+	60
.....	T. 8 S., R. 2 E., sec. 15.....	2	374	+	1
.....	.....do.....	6	380	+	60
.....	.....do.....	2	400	+	30
.....	.....do.....	.....	500	+	60
al.....	.....do.....	3	373	+	(?) 118
ı.....	T. 8 S., R. 2 E., sec. 16.....	1¼	160	−	.....
.....	.....do.....	2	380	+	3
	T. 8 S., R. 2 E., sec. 18.....	2	450	+	.....
	.....do.....	2	412	+	30
.....	T. 8 S., R. 2 E., sec. 19.....	2	387	+	15
.....	.....do.....	2	170	+	6
.....	.....do.....	1¼	130	+	2
.....	.....do.....	1½	45	+	3
.....	T. 8 S., R. 2 E., sec. 20.....	2	475	+	10
.....	T. 8 S., R. 2 E., sec. 21.....	2	333	+	16
.....	.....do.....	1¼	250	+	8
.....	.....do.....	2	560	+	20
.....	.....do.....	2	400	+	10
	T. 8 S., R. 2 E., sec. 22.....	1½	286	+	.....
	.....do.....	1¼	.....	+	6
.....	T. 8 S., R. 2 E., sec. 23.....	2	385	+	8
.....	.....do.....	2	360	+	35
.....	.....do.....	3	250	− 6	.....
	T. 8 S., R. 2 E., sec. 25.....	2	137	+	35
.....	T. 8 S., R. 2 E., sec. 26.....	2	318-320	+	64
.....	.....do.....	2	390	+	14
	T. 8 S., R. 2 E., sec. 27.....	2	.....	+	60
.....	.....do.....	2	425	+	35
.....	T. 8 S., R. 2 E., sec. 28.....	1¼	385	+	5
.....	.....do.....	2	415	+	.....
.....	T. 8 S., R. 2 E., sec. 29.....	2	450	+	.....
	.....do.....	2	175	+	8
.....	.....do.....	1½	.....	+	20
.....	.....do.....	1½	.....	+	10

[a] Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

Name of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
Stewart's ranch	T. 8 S., R. 2 E., sec 29	2	.....	+	5
C. Hickman	do	2	172	+	15
S. P. Lorensen	do	2	163	+	25
P. J. Lundale	T. 8 S., R. 2 E., sec. 32	1½	175	+	1
J. Howe	T. 8 S., R. 2 E., sec. 33	2	200	+	1
J. J. Hansen	do	2	380	+	20
G. Staley	do	2	185	+	20
Do	do	2	380	+	35
W. O. Creer	T. 8 S., R. 2 E., sec. 35	1½	20	+	10-25
Creamery	T. 8 S., R. 3 E., sec. 4	2	144	+	30
J. Anderson	T. 8 S., R. 3 E., sec. 5	2	145	+	.....
M. C. King	T. 8 S., R. 3 E., sec. 7	2	170	+	30
Do	do	2	154	+	12
(a)	T. 8 S., R. 3 E., sec. 8	1½	30	+	2-3
Sugar factory	do	2	123	+	10
T. B. Jones	T. 8 S., R. 3 E., sec. 21	.....	22	−15	.....
(a)	T. 8 S., R. 3 E., sec. 30	1¼	140	+	2
H. A. Harlan	do	1¼	30	+	1½
J. P. Holt	do	1¼	100	+	1½
J. G. Robertson	do	.....	.....	+	.....
G. LeBaron	T. 9 S., R. 1 E., sec. 7	.....	.....	+	.....
McBeath	T. 9 S., R. 1 E., sec. 12	2	360	+	27
J. Webb	T. 9 S., R. 1 E., sec. 13	1½	247	+	.....
F. Rouse	T. 9 S., R. 1 E., sec. 32	2	180	.....	8
J. E. Gardner	T. 9 S., R. 2 E., sec. 1	1½	290	−	.....
(a)	do	1¼	155	+	.....
(a)	T. 9 S., R. 2 E., sec. 2	1¼	200	+	.....
(a)	do	2	200	+	.....
(a)	T. 9 S., R. 2 E., sec. 3	2	160	+	30
(a)	do	.....	375	+	.....
(a)	do	2	228	+	(?) 125
S. Douglas	T. 9 S., R. 2 E., sec. 5	2	50	+ 15	.....
Do	do	.....	130	.....	30
Dixon Bros.	do	2	300	+	(?) 100
P. Windward	do	2	140	+ 1	55
T. E. Daniels	T. 9 S., R. 2 E., sec. 6	2	116	+ 20	.....
C. Long	do	2	160	+	37
D. LeBaron	T. 9 S., R. 2 E., sec. 7	2	217	−	.....
(a)	T. 9 S., R. 2 E., sec. 10	.....	438	.....	3
A. Bingham	T. 9 S., R. 2 E., sec. 11	1¼	196	+	15
Do	do	2	275	+	8
Creamery	do	.....	225	+	.....
C. Hanks	do	2	175	+	10
A. Burke	do	2	296	+	25
J. Sheen	do	2	279	.....	35
O. R. Thomas	T. 9 S., R. 2 E., sec. 29	.....	20	−16½	.....
H. Boyle	T. 9 S., R. 2 E., sec. 30	2	90-126	+	15-30
J. Job	T. 9 S., R. 1 W., sec. 25	1¼	50- 60	+	12
Do	T. 9 S., R. 1 W., sec. 26	1¼	220	+	.....
W. M. Phillippi	T. 9 S., R. 1 W., sec. 33	2	165	−125	.....
(a)	T. 9 S., R. 1 W., sec. 35	2	200	+	½
Rudd estate	T. 9 S., R. 1 W., sec. 36	2	58	+	2
A. Steele	T. 10 S., R. 1 E., sec. 6	.....	85	+	7-8
E. Hawkins	T. 10 S., R. 1 E., sec. 17	2	130	− 80	.....
H. Johnson	T. 10 S., R. 1 W., sec. 2	.....	407	− 9	.....

a Owner's name unknown.

Wells in Jordan River and Utah Lake valleys—Continued.

ne of owner.	Location.	Diameter.	Depth.	Height of water.	Yield per minute.
		Inches.	*Feet.*	*Feet.*	*Gallons.*
Phillippi	T. 10 S., R. 1 W., sec. 4	2	168	–	
lbertson	T. 10 S., R. 1 W., sec. 9	2	178	–	
	do	2	307	–100	
	do	2	300	–	
	do	2	420	–	
berry	T. 10 S., R. 1 W., sec. 11	2	77	– 3	
(a)	T. 10 S., R. 1 W., sec. 12		412	–	
ry	do		70	– 4	
ande Western	do		334	– 4	
h	T. 10 S., R. 1 W., sec. 14	2	160	–	
homas	T. 10 S., R. 1 W., sec. 15		8	–	
Wells	do	1¼	50	– 3	
	do	2	70	– 20	
s	do	2	60	–	
ook	do	2	53	– 7	
	T. 10 S., R. 1 W., sec. 21	2	a116	– 86	
	T. 10 S., R. 1 W., sec. 30	2	238	–222	
(a)	T. 10 S., R. 1 W., sec. 33	2	138	–	

a Owner's name unknown.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON THE

EOLOGY AND UNDERGROUND WATERS OF THE ROSWELL ARTESIAN AREA NEW MEXICO

BY

CASSIUS A. FISHER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1906

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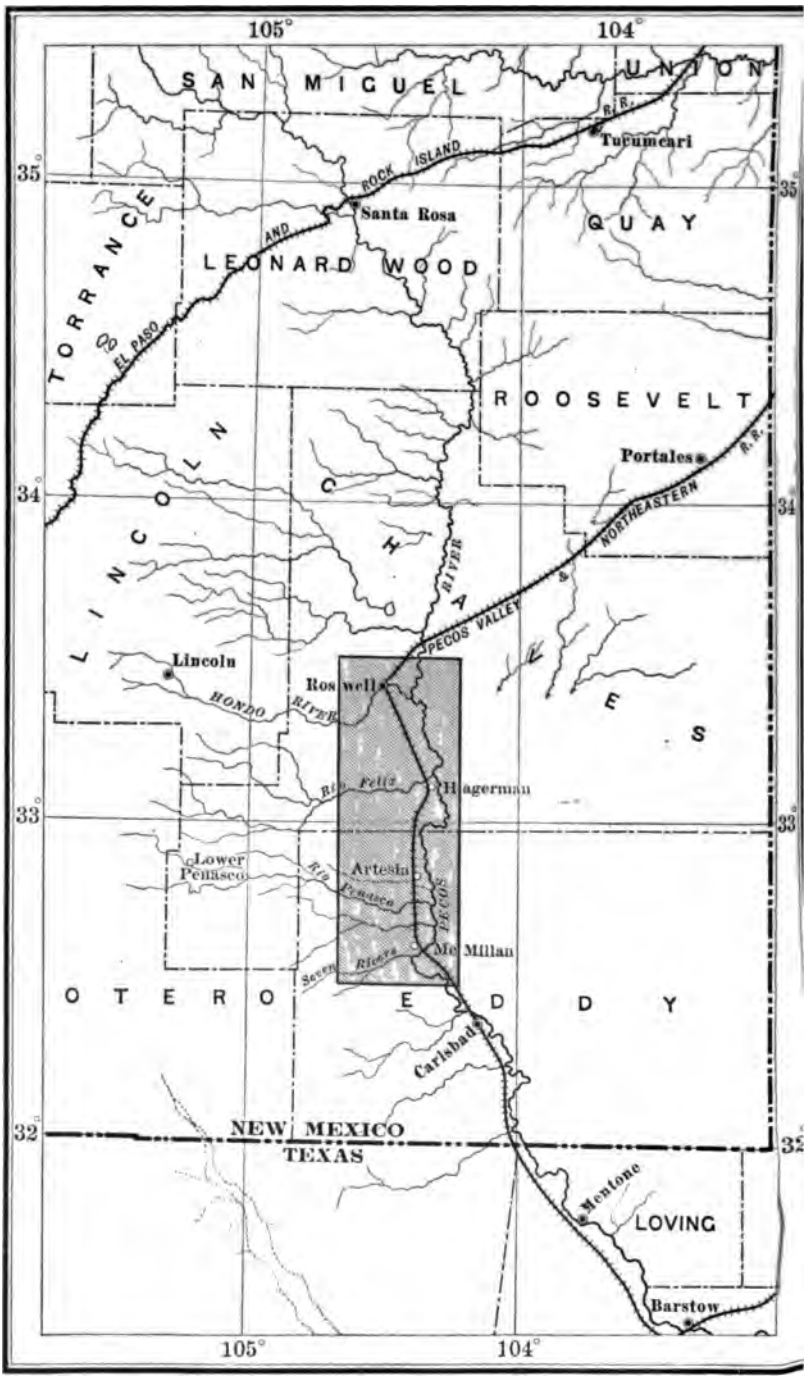


MAP SHOWING GENERAL LOCATION OF THE ROSWELL ARTESIAN AREA.

LIMINARY REPORT ON THE GEOLOGY AND UNDERGROUND WATERS OF THE ROSWELL ARTESIAN AREA, NEW MEXICO.

By Cassius A. Fisher.

INTRODUCTION.

he area to which this report relates is located in southeastern New Mexico. It comprises ut 1,800 square miles lying along Pecos River and extending from a point 5 miles north Roswell to below the mouth of Seven Rivers, as shown in Pl. I. In addition to the discus- n of the artesian waters, the report includes a brief description of the geology of the sedi- ntary rocks, their structure, and their relation to the underground waters. The area of ring wells is indicated on the map, Pl. VI, and records of representative wells are given, ich are intended to illustrate the character and succession of the water-bearing beds) ormation respecting surface waters available for domestic and irrigation purposes and rief description of the climatic and agricultural features of the region are also given.

he investigation was conducted under the direction of Mr. N. H. Darton.

he writer was assisted in the field by Messrs. E. M. Mitchell and E. Patterson, and these tlemen obtained a portion of the well data upon which this report is based. The system- measurement of well pressures was carried on under the direction of Mr. W. M. Reed, rict engineer of the Reclamation Service, who has done much to promote the work. The mical analyses of the surface and artesian waters have been kindly furnished by Mr. d. Skeats, of El Paso, Tex., and the paleontological collections have been examined by G. H. Girty. I am indebted to Messrs. Hagerman, Goodart, Phillips, Hortenstein, rlock, Hale, and others for information concerning artesian irrigation.

n excellent report on the soils of the Roswell basin by Messrs. T. H. Means and F. D. dner was used in the preparation of this report.

TOPOGRAPHY.

lief.—The topographic features of the Roswell basin present little variety. Across the side of the district there are irregular bluffs rising 200 to 300 feet above Pecos River, to the west the surface rises gradually toward the high limestone plateau bordering apitan, Sierra Blanca, and Sacramento mountains. The region has an average eleva- of 3,600 feet above sea level. The highest portion is along the west side of the district, e the altitude is about 4,000 feet. In the southeast corner the altitude is about 3,200 Near the junction of the North and South forks of Seven Rivers there is a high bluff ig a north-facing escarpment, which rises high above the valley of the South Fork, and e north side of Eagle Draw is a small but prominent plateau.

ainage.—The principal drainage channel is Pecos River, which enters from the north lows in a southerly direction across the district. The flow is not large, but it carries a amount of water during the entire year. There are a number of tributaries from the the largest being the Hondo, Felix, Penasco, and Seven rivers. Hondo and Penasco s, *perennial streams throughout* their upper courses, have their sources high on the

slopes of the Capitan, Sierra Blanca, and Sacramento mountains. The Felix and Seven rivers rise in the limestone plateaus lower down, and drain a much smaller area. Hondo River east of Roswell is joined on the north by North Spring and Berrendo rivers, and on the south side near its mouth by South Spring River. These streams are fed by springs, and they carry abundant water at all seasons. There are also several small intermittent streams which enter Pecos River. Those from the west are Gardners Arroyo, Fourmile Creek, Eagle Draw, Cottonwood Creek, Walnut Draw, and Zuber Hollow; those from the east are Comanche Draw and Long Arroyo.

Lakes.—At the heads of North and South Spring rivers and Middle and South Berrendo rivers are lakes of moderate size. These lakes are fed by a number of small springs, which derive their water mainly from the unconsolidated deposits underlying Hondo, Blackwater, and Eden valleys. Water rises to the surface in the lower courses of Felix River, Cottonwood Creek, Penasco River, Gardners Arroyo, and North and South Forks of Seven Rivers. In the vicinity of Lake Arthur, Hagerman, Greenfield, and Dexter, and north along the east side of the Northern canal there are lakes fed in part by springs and in part by seepage from the Northern canal.

On the east side of Pecos River, about 12 miles southeast of Roswell, are several deep lakes lying along the base of the gypsum bluffs, which are locally known as the "Bottomless Lakes." Dimmit Lake, the largest of these, is situated at the head of a short ravine about 2½ miles from Pecos River. Near the mouth of this ravine, on the north side, is Dee Lake, and along the base of the bluffs for some distance to the north several smaller lakes occur. The location of these lakes is shown on the geologic map, Pl. IV. They have probably been formed by flood water from the high slopes to the east, which, in flowing over the exposed gypsum ledges at the edge of the bluffs, has dissolved the gypsum and formed subterranean passages that now extend to some of the shallow artesian flows in Pecos Valley. A view of one of the "Bottomless Lakes" is shown in Pl. III, *A*. The water from some of these lakes is used for irrigation.

OUTLINE OF GEOLOGIC RELATIONS.

GENERAL STATEMENTS.

The rocks of the district comprise limestone, sandstone, clay, and gypsum which are believed to be of Permian age. Overlying these deposits throughout the Roswell basin are extensive sheets of sand, gravel, clay, and silt, probably of Quaternary age, which have been deposited in successive terraces between Pecos River and the high limestone slopes to the west. The so-called Permian series of this district consists of an upper red bed member of gypsum, red sand, limestone, and clay 600 to 800 feet thick, forming the high bluffs along the east side of Pecos River and underlying the recent deposits of Pecos Valley, and a lower member of massive limestone, clay, and gypsum of undetermined thickness, which constitutes high rugged slopes to the west. Overlying the red-bed division east of Pecos River is a reddish-brown sandstone about 100 feet thick, which may be of Cretaceous age. No subdivisions have been made of the probably Permian rocks in this region in the present reconnaissance.

PERMIAN (?) SERIES.

Red-bed division.—These rocks consist of alternating beds of gypsum, red sand, and cl[illegible] with an occasional layer of dark-gray, compact limestone. The gypsum predomin[illegible] and usually occurs in beds about 10 feet thick. It is often found, however, in thinner l[illegible]ers, interbedded with clay and limestone. The red beds are provisionally placed in [illegible] Permian, although no fossils have been found in them. They are not shown separat[illegible] on the geologic map (Pl. IV), but are represented with the underlying massive limeston[illegible] The upper part of the beds is well exposed in the bluffs along the east side of Pecos Riv[illegible] where a number of sections have been measured. These sections are as follows:

A HEAD OF NORTH SPRING RIVER.

B HEAD OF SOUTH SPRING RIVER.

A. VIEW OF "BOTTOMLESS LAKES," EAST OF PECOS RIVER.

B. ARTESIAN WELL AND RESERVOIR EAST OF SOUTH SPRING, NEW MEXICO.

Sections of gypsum bluffs along the east side of Pecos River, New Mexico.

	Feet.
East of Roswell:	
Alternating layers of gypsum and red sand, with an occasional layer of limestone	50
White gypsum	6
Red sand	6
White, thin-bedded gypsum	10
Red sandstone containing thin layers of limestone	24
White gypsum	5
Red sand	13
Gypsum	10
Red sand	3
Gypsum	8
Red sand	8
Gypsum	4
Greenish-gray sandstone	25
Gypsum	6
Total	178
At Dimmit Lake:	
Gray, sandy limestone	20
Alternating layers of gypsum and red and green clay, with an occasional bed of porous limestone	100
Gypsum	4
Red clay	2½
Gypsum	18
Alternating layers of gypsum and red clay	6
Gypsum	11
Alternating layers of gypsum and red sandstone	6
Gypsum	9
Red clay	1
Gypsum	10
Alternating layers of gypsum and red clay	15
Gypsum	5
Red clay	1½
Gypsum	10
Red clay	7
Alternating layers of gypsum and red clay	8
Gypsum	6
Red clay, with thin layers of gypsum	3
Gypsum	6
Total	249
Eight miles northeast of Artesia:	
Gray, compact limestone	5
Gypsum and red, sandy clay in alternate succession	65
Red, sandy clay	10
White, massive gypsum	15
Red, sandy clay	5
White gypsum	10
Gray limestone	5
Gypsum	18
Red clay	12
Gypsum	5
Total	150
About 2 miles southeast of the mouth of South Fork of Seven Rivers:	
Massive, gray limestone	35
Gypsum and red sandstone in alternate layers, with an occasional limestone ledge	50
Gypsum, thin-bedded porous limestone, and red sandstone arranged alternately, the gypsum predominating	150
Gypsum, with thin layers of gray limestone	50
Total	285

Limestone division.—The massive limestone beds underlying the so-called Permian red beds of this region consist mainly of gray, compact limestone, with layers of soft sandstone, clay, and gypsum. In the upper part the limestone is more or less thin-bedded and

porous, and contains many sandy layers. From these beds some of the strongest arte flows in the Roswell basin are obtained. Limestone outcrops along the west side of the trict, and farther to the west forms high rugged plateaus, extending toward the mounta Fossils are not abundant in the formation, but in one locality northwest of Roswell a nu ber were collected, which consisted mainly of *Schizodus* and *Pleurophorus*, preserved casts. According to Doctor Girty the fauna and lithology of these specimens suggest highest Carboniferous beds or the Permian of the Mississippi Valley in Texas.

To the east of the Roswell district the high plains are traversed by dikes of igneous ro One of these dikes extends into the area in the northeast corner, but passes beneath t surface at a point about 5 miles east of Pecos River. Its location is shown on the geolo map (Pl. IV). The dike is about 35 feet wide, and consists of a light-colored rock, whi is much decomposed on the surface.

Extending across the southeast portion of the area, from below Lake McMillan to t high bluffs east of Artesia, is a narrow zone in which the sedimentary rocks are more or l metamorphosed, so that in the crevices considerable mineralization has taken place. Co per is the principal mineral, occurring mainly as the carbonate and oxide. Some prospe ing has been done in the hills south and east of Artesia, but no paying ore has been covered.

CRETACEOUS (?) SYSTEM.

The sandstone overlying the Permian (?) red beds along the east side of the distri possibly, as above stated, of Cretaceous age. A few fossil plants were found in these but they were too fragmentary to be determined. The distribution of the formation not ascertained. It consists of massive, reddish-brown sandstone in beds of varying t ness, with an occasional layer of light-gray sandstone. The material is coarse grained cross-bedded throughout, and often weathers into rounded forms. The following is a tion of the sandstone near Petty's windmill, about 15 miles northeast of Roswell:

Section of sandstone overlying Permian (?) red beds near Roswell, N. Mex.

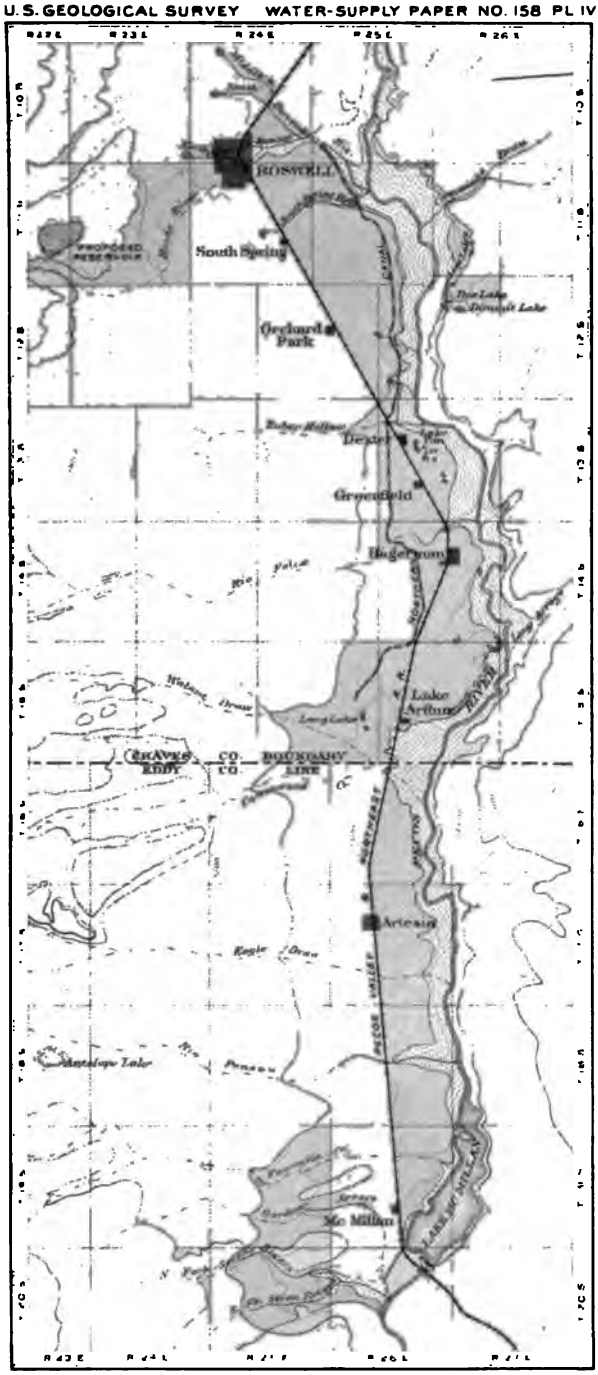
Reddish-brown, cross-bedded sandstone	
Brown, massive sandstone	
Lighter brown, massive sandstone, somewhat cross-bedded	
Gray, coarse-grained sandstone	
Reddish-brown sandstone	

QUATERNARY SYSTEM.

The formations of the Quaternary period cover an extensive area in the Roswell b comprising approximately 1,200 square miles. They occupy the entire central portio the basin, and extend far up the limestone slopes to the west. These deposits are ma of two kinds—the alluvium of the river valleys and the unconsolidated material of hi levels.

Alluvium.—The alluvium is confined mainly to Pecos River Valley, although small a occur along all the larger and many of the smaller streams. It is a light-colored, grained material, consisting mainly of sand, gravel, and clay, with a small amount o ganic matter. In the lower portions of the valley the soil contains much "alkali," o sufficient to render it unfit for cultivation. There are many small lakes along the r bottom, and the lowlands are generally swampy. On the east side of Pecos River, fro point opposite Dexter to beyond Comanche Draw, there are several springs, which b built cones of spring deposits 6 to 10 feet high.

Hondo, Felix, and Penasco rivers have built small flood plains along their lower cou which are perceptibly higher than the surrounding region. The alluvium along t streams varies somewhat in character, but it is generally of a light-gray color, and cons of gravel, sand, silt, and clay, covered by a fertile soil. The fertility is due to the prese of fine silt brought down by the flood waters from the high mountain rgeions. Accor



RECONNAISSANCE GEOLOGIC MAP OF THE ROSWELL ARTESIAN BASIN, SOUTHEASTERN NEW MEXICO

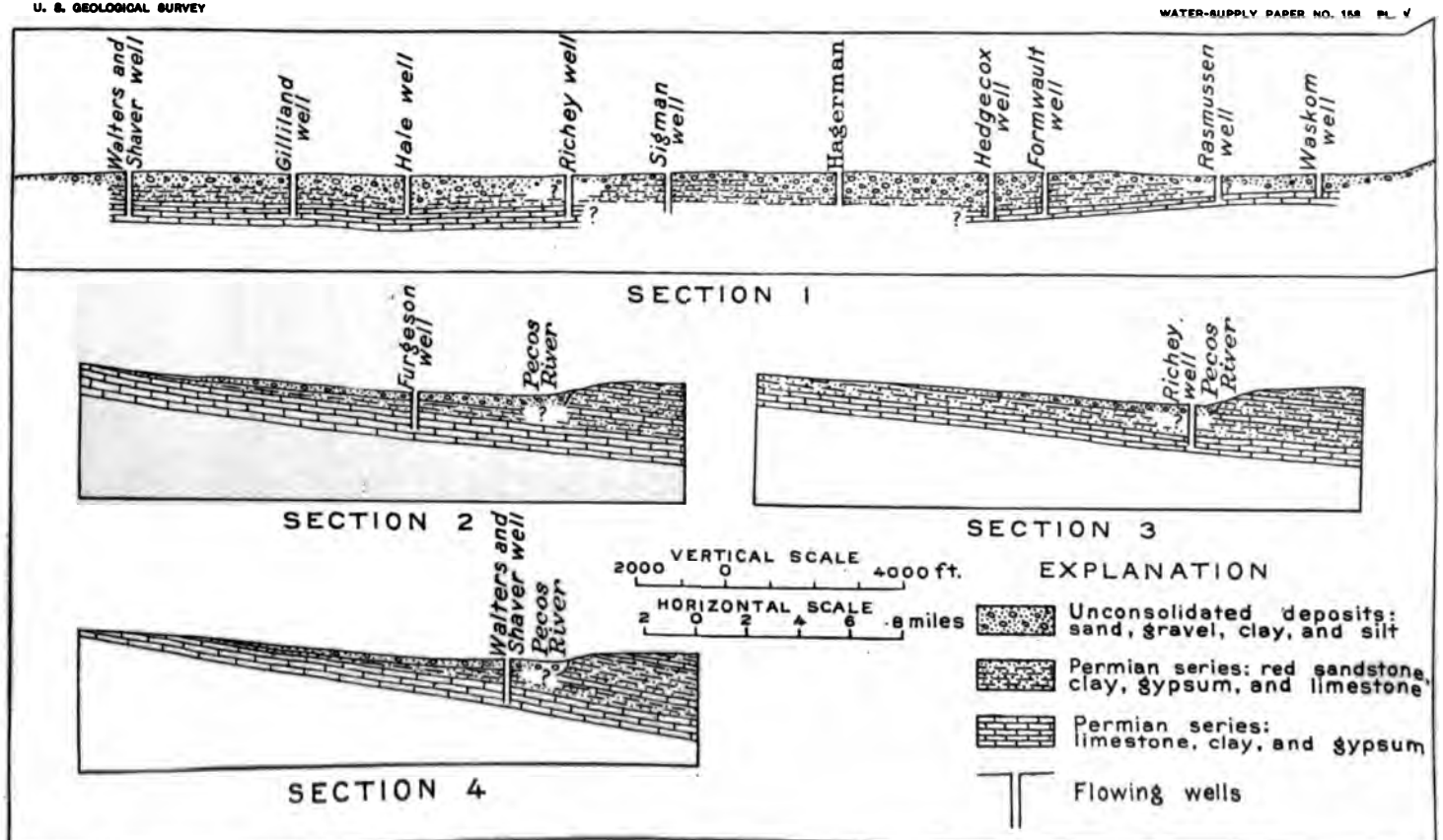
BY C. A. FISHER

Topography compiled from railroad data and barometer readings

Scale

Contour interval 100 feet

1905



GEOLOGIC SECTIONS ACROSS THE ROSWELL ARTESIAN BASIN

to Mr. T. H. Means the alluvium of Hondo Valley contains more plant food than that of the Nile in Egypt. The following analyses are taken from Mr. Means's report:[a]

Chemical composition of Hondo and Nile sediment.

Constituent.	Hondo mud (Skeats).	Nile mud (Mackenzie).	Constituent.	Hondo mud (Skeats).	Nile mud (Mackenzie).
Insoluble matter and silica	43.6	58.17	Soda		.62
Iron oxide and alumina	21.4	24.75	Sulphuric acid	1.96	.20
Oxide of manganese		.09	Phosphoric acid	.3	.21
Magnesia	2.1	2.42	Carbonic acid		1.55
Lime	5.7	3.31	Organic matter	9.8	8.00
Potash	1.19	.68	Nitrogen in organic matter	.32	.12

Unconsolidated deposits.—These deposits consist mainly of sand, gravel, and clay. The sand is of light-gray color, medium to fine grained, the clay more or less sandy, and the gravel a moderately coarse variety. The gravel is often firmly cemented by calcium carbonate, and local deposits of gypsum and a calcareous material known as "caliche" occur throughout the formation. According to well records the thickness of the formation varies considerably in different parts of the basin. In several deep wells around Artesia coarse gravels were encountered 500 to 700 feet below the surface. At Roswell and in the lower part of Hondo Valley unconsolidated sediments are 150 to 300 feet thick, and in Seven Rivers Valley they are probably thicker. In John Richey's well, 8 miles northeast of Artesia, a gravel bed, apparently the base of the unconsolidated sediments, was penetrated at a depth of 134 feet. At Sigman's well, near Lake Arthur, according to the driller's statement, the unconsolidated deposits are only a few feet thick, and about 3 miles northeast of Lake Arthur the red, sandy beds of the Permian (?) are exposed.

ARTESIAN WATER HORIZONS.

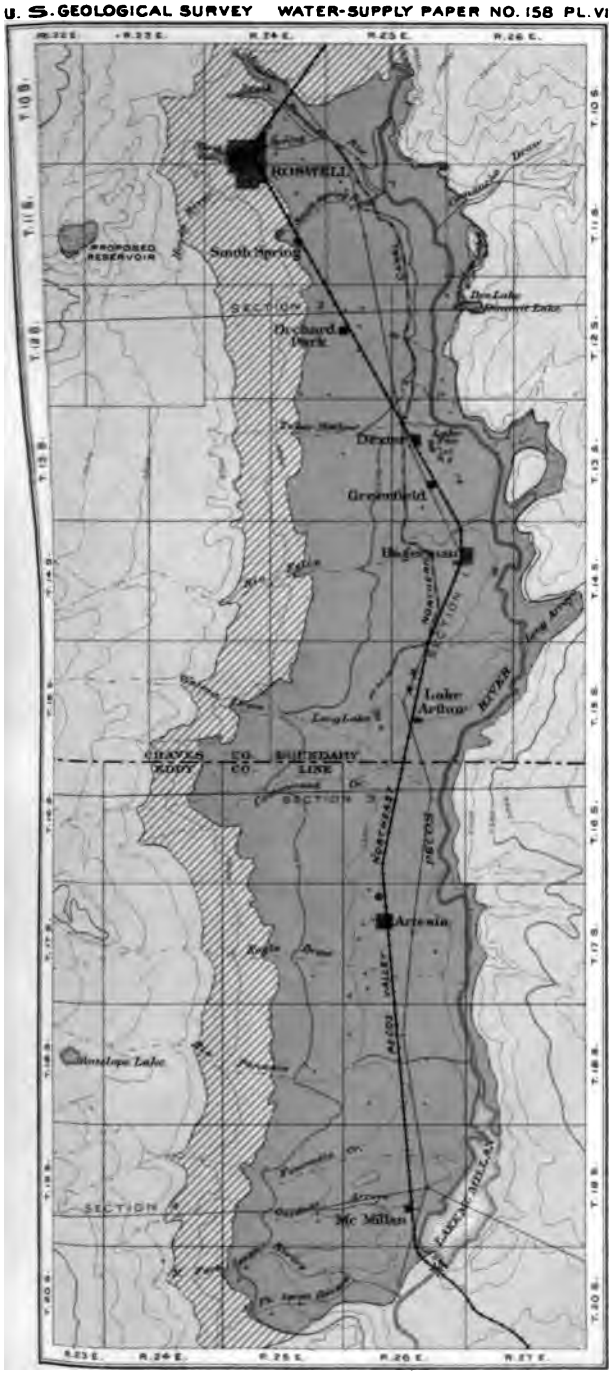
There are several artesian horizons in the formations underlying the Roswell basin. Flows of moderate volume are found in the sandstones of the upper member of the Permian (?) series and in the overlying unconsolidated deposits, but the strongest are from porous limestones interstratified with beds of sand, which constitute the upper part of the massive limestone division.

EXTENT OF ARTESIAN AREA.

The Roswell artesian basin is about 60 miles long and has an average width of 11 miles. At the north end it is relatively narrow, but to the south it widens somewhat. It comprises about 650 square miles, the greater part of which lies along the west side of Pecos River. The area of flow is shown on Pl. VI.

In the vicinity of Roswell the head of artesian water, as determined both by practical tests and by the pressures of a number of flows in the town of Roswell, is sufficient to raise water to an altitude of 3,586 feet above sea level, the exact elevation of the water level in the head of North Spring River. In order to ascertain the western limit of the area of flow south of Roswell a line of levels was surveyed, under the direction of Mr. W. M. Reed, district engineer, from the head of North Spring River as far south as Eagle Draw. From there to Seven Rivers the western boundary of the artesian basin was ascertained mainly from evidence of wells in the adjoining lowlands. It is possible that the artesian head increases to the west and that flows might be obtained higher up the slopes than is indicated on the artesian water sheet, especially in the valleys of Felix River, Cottonwood Creek, and Penasco River, but there appears to be no definite evidence of this. The eastern limits of the artesian area

[a] Means, T. H. and Gardner, F. D., Soil survey in the Pecos Valley: Field operations of Bureau of Soils, 1899, *U. S. Dept. Agric., Rept. No. 64*, 1900, p. 49.



LEGEND

Artesian area

Approximate area of irrigable land in which water would probably rise in deep wells within 100 feet of the surface

Non artesian area

Flowing wells

MAP OF THE ROSWELL ARTESIAN BASIN
SOUTHEASTERN NEW MEXICO

BY C. A. FISHER

Topography compiled from railroad data and barometer readings

Scale

5 0 5 10 15 20 Miles

Contour interval 100 feet

1905

Partial list of artesian wells in Roswell district, New Mexico—Continued.

Name of owner and location.	Depth.	Diameter.	Yield.[a]
	Feet.	*Inches.*	*Galls. per minute.*
Chaves Co., block 11, Roswell	206	5⅝	675
Church, J. P., lot 8, block 45, West Roswell	270	5⅝	500
Cottingham, J. A., lot 13, block 19, original Roswell	202	5⅝	600
Davis, W. P., SE. ¼ NE. ¼ sec. 7, T. 11 S., R. 25 E	450	5⅝	500
Denning, S. P., lot 8, block 51, west side Roswell	240	5⅝	580
Diamond ice factory, lot 1, block 7, Thurber's addition, Roswell	196	5⅝	700
Dickson, J., northwest corner Washington and 2d sts., Roswell	270	5⅝	600
Dickson, J. M., lot 5, block 52, west side Roswell	198	5⅝	400
Divers, F., lot 2, block 9, west side Roswell	232	5⅝	600
Dunn, G., T. 12 S., R. 26 E	264	6⅝	410
Evans, J. F., lot 8, block 28, original Roswell	200	4	250
Elliott Bros., SW. ¼ SW. ¼ sec. 32, T. 12 S., R. 25 E	859	6	612
Faulkner, R. L., lot 10, block 12, west side Roswell	198	5	500
Ferguson, W. M.:			
Lot 10, block 2, original Roswell	255	4½	320
NE ¼ NW. ¼ sec. 15, T. 12 S., R. 25 E	882	6⅝	987
Finley, M. N., SW. ¼ SW. ¼ sec. 3, T. 11 S., R. 24 E	354	7⅝	150
Fitzgerald & Kingston, lot 1, block 17, original Roswell	200	5⅝	600
Fitzgerald, lot 12, block 26, original Roswell	190	5⅝	500
Frank, C. J., lot 9, block 10, original Roswell	202	5⅝	600
Garrett, A. D., lot 1, block 20, west side Roswell	260	5⅝	500
Garst, J., lot 2, block 1, original Roswell	271	3	250
Garst, Julius, SE. ¼ SW. ¼ sec. 28, T. 10 S., R. 24 E	279	6⅝	.....
Gaslin, H., lot 10, block 48, west Roswell	242	4½	350
Gaullier, lot 6, block 1, original Roswell	265	5⅝	680
Goodart, J. H., NW. ¼ NE. ¼ sec. 7, T. 11 S., R. 25 E	400	4⅝	600
Hagerman, O., lot 3, block 24, South Roswell	405	5	680
Hamilton, R. S., lot 12, block 14, original Roswell	301	5⅝	800
Hamilton, J., SW. ¼ SW. ¼ sec. 26, T. 10 S., R. 24 E	313	6⅝	400
Haynes, C. W.:			
Lot 7, block 20, South Roswell	310	5⅝	750
Roswell	232	5⅝	750
Do	204	7⅝	750
Do	232	5⅝	700
Henning, J. H., lot 7, block 11, west side Roswell	235	5	400
Hinkle, J., lot 7, block 51, west side Roswell	235	4½	400
Hobson, Lowe & Co., lot 9, block 3, original Roswell	270	5⅝	600
Hortenstein, NW. ¼ SW. ¼ sec. 23, T. 12 S., R. 25 E	840	5⅝	340
Jaffa, N., lot 10, block 3, Thurber's addition, Roswell	200	3	200
Jaffa & Prager, lot 13, block 14, Roswell	380	4	450
Johnson, R. W., lot 7, block 24, west side Roswell	250	5⅝	750
Lawndes, G., NW. ¼ NW. ¼ sec. 35, T. 11 S., R. 25 E	287	.....	300
Lea, J. C., lot 5, block 4, original Roswell	230	6⅝	750
L. F. D. stock farm SE. ¼ NW. ¼ sec. 1, T. 11 S., R. 24 E	383	6⅝	506
	333	4½	100
McCarty, S. S., N. ½ NW. ¼ sec. 14, T. 10 S., R. 25 E	844	5⅝	300
McClenney, M. E., SE. ¼ SE. ¼ sec. 35, T. 10 S., R. 24 E	375	7⅝	600
Marrow & Tannehill, lot 14, block 13, old Roswell	260	5	500
Meeks, W., lot 6, block 28, original Roswell	160	4	250
Miller, J., lot 4, block 30, original Roswell	230	5⅝	580
New Mexico Military Institute, Roswell	232	6⅝	.....
Parsons, R. M., lot 5, block 54, west side Roswell	245	5⅝	675
Patterson, J. F., lot 1, block 42, west side Roswell	260	3	250

[a] Mainly estimated.

ed at a much greater depth. The formations encountered in sinking a well at Roswell lly consist of unconsolidated deposits for the first 175 feet from the surface. Below epth drills penetrate bed rock, composed of hard, light-colored limestone underlain by ating layers of porous limestone and sandstone. The following are records of repre- ive wells in and near Roswell:

Typical well records in and near Roswell, N. Mex.

	Feet.
l of the Ogle well at Roswell:	
l	0- 5
avel	5- 30
eish clay with layers of gravel	30-150
enish-yellow clay with rust-colored bands	150-162
t red sandstone (water bearing)	162-170
clay	170-174
y limestone	174-177
clay	177-178
y limestone	178-182
y limestone, very hard	182-186
gray limestone	186-204
d gray limestone	204-218
t-gray, porous limestone (water bearing)	218-226
estone and sandstone in alternate layers (water bearing)	226-242
of the Waskom well, SW. ¼ sec. 32, T. 10 S., R. 25 E.:[a]	
	0- 5
l and gravel	5- 15
ow clay	15- 40
and decomposed gypsum	40- 70
stone, coarse yellow sand, and gravel in alternate succession	70-360
estone and sandstone in alternating layers, the limestones predominating	360-560
of the Rasmussen well, SW. ¼ sec. 21, T. 11 S., R. 25 E.:	
and fine sand	0- 30
sand	30- 40
el	40- 50
and gravel in alternate layers	50- 60
sand	60- 65
sand and hard rock in thin layers	65-172
ksand	172-212
sandstone	212-327
sand containing layers of rock	327-400
estone	400-560

Partial list of artesian wells in Roswell district, New Mexico.

Name of owner and location.	Depth.	Diameter.	Yield [b]
	Feet.	Inches.	Galls. per minute.
on:			
¼ sec. 3, T. 11 S., R. 25 E	60	6	.....
Do	60	6	.....
Do	58	6	.....
on & Skillman, lot 7, block 16, West Roswell	440	4	400
nless Lake" well, SE. ¼ NW. ¼ sec. 10, T. 12 S., R. 26 E	420	6	.....
& Beal, lot 6, block 53, West Roswell	232	5⅝	600
ritz, lot 14, block 23, west side Roswell	235	5⅝	500
& Creighton, lot 11, block 4, original Roswell	238	5⅝	500
E. A.:			
. ¼ NW. ¼ sec. 34, T. 10 S., R. 24 E	340	4½	402
6, block 21, west side Roswell	229	4	250
rs, R. M., lot 4, block 24, original Roswell	244	4⅝	600
on, D., NW. ¼ NW. ¼ sec. 27, T. 10 S., R. 24 E	330	7⅝	300

[a] In this well, located 4 miles east of Roswell, bed rock was reached at a depth of 360 feet.
[b] Mainly estimated.

yield are obtained in soft sandstones at depths of 300 to 500 feet, but on the higher slo to the west the main flow occurs in porous limestones 800 to 1,000 feet below the surfa The Hedgecoxe well, about 1 mile southeast of Dexter, is 960 feet deep. The main fl occurs in a porous limestone underlying red sandstone 60 feet thick, which is overlain unconsolidated material.

The following records of wells were furnished by the drillers:

Typical deep borings in Hagerman district, New Mexico.

	Feet.
Record of the Hedgecoxe well, near Dexter:	
Soil and gravel	0-
Coarse sand	19-
Quicksand	71-
Limestone	271-
Red sandy clay	273-
Yellow clay	323-
Limestone	343-
Quicksand	345-
Limestone	545-
Blue clay	551-
Quicksand	601-
"Shell rock"	651-
Alternating layers of sand, silt, and clay	653-
Coarse gravel	800-
Red sandstone	806-
Porous limestone	866-
Record of Widdem...a well:	
Soil	0-
Gravel	20-
Quicksand	55-
Alternating beds of clay and gypsum	105-
Sand	360-
Red sand with layers of clay and one 25-foot layer of gypsum near the middle	440-
Limestone	800-1,0
Record of Cummins well:	
Soil and gravel	0-
Sand	40-
Clay	44-
Gravel	60-
Rock, clay, and sand in alternate layers	65-
Clay and sand	105-
Red sand	165-
Coarse red sand and clay in alternate layers	550-
Limestone	820-
Partial record of town well at Hagerman:[a]	
Soil	1-
Conglomerate	12-
Sand	22-
Clay	32-
Alternating beds of coarse sand and gravel	60-
Gypsum and red sandy clay in alternate beds	535-
Gypsum	610-
Red clay and sand	630-
Hard gypsum	675-
Hard, gray sandstone	732-
Gypsum	735-
Red clay and sand	745-
Gypsum	750-

[a] Boring in progress at time investigation was made.

A. RASMUSSEN'S WELL, EAST OF SOUTH SPRING, NEW MEXICO.

B. WIDDEMAN'S WELL NEAR DEXTER, N. MEX.

yield are obtained in soft sandstones at depths of 300 to 500 feet, but on the higher slopes to the west the main flow occurs in porous limestones 800 to 1,000 feet below the surface. The Hedgecoxe well, about 1 mile southeast of Dexter, is 960 feet deep. The main flow occurs in a porous limestone underlying red sandstone 60 feet thick, which is overlain by unconsolidated material.

The following records of wells were furnished by the drillers:

Typical deep borings in Hagerman district, New Mexico.

	Feet.
Record of the Hedgecoxe well, near Dexter:	
Soil and gravel	0- 19
Coarse sand	19- 71
Quicksand	71- 271
Limestone	271- 273
Red sandy clay	273- 323
Yellow clay	323- 343
Limestone	343- 345
Quicksand	345- 545
Limestone	545- 551
Blue clay	551- 601
Quicksand	601- 651
"Shell rock"	651- 653
Alternating layers of sand, silt, and clay	653- 800
Coarse gravel	800- 806
Red sandstone	806- 866
Porous limestone	866- 960
Record of Widdem[illegible] well:	
Soil	0- 20
Gravel	20- 55
Quicksand	55- 105
Alternating beds of clay and gypsum	105- 370
Sand	370- 440
Red sand with layers of clay and one 25-foot layer of gypsum near the middle	440- 800
Limestone	800-1,000
Record of Cummins well:	
Soil and gravel	0- 40
Sand	40- 44
Clay	44- 60
Gravel	60- 65
Rock, clay, and sand in alternate layers	65- 105
Clay and sand	105- 165
Red sand	165- 550
Coarse red sand and clay in alternate layers	550- 820
Limestone	820- 840
Partial record of town well at Hagerman:[a]	
Soil	1- 12
Conglomerate	12- 22
Sand	22- 32
Clay	32- 60
Alternating beds of coarse sand and gravel	60- 535
Gypsum and red sandy clay in alternate beds	535- 610
Gypsum	610- 630
Red clay and sand	630- 675
Hard gypsum	675- 732
Hard, gray sandstone	732- 735
Gypsum	735- 745
Red clay and sand	745- 750
Gypsum	750- [illegible]

[a] Boring in progress at time investigation was made.

A. RASMUSSEN'S WELL, EAST OF SOUTH SPRING, NEW MEXICO.

B. WIDDEMAN'S WELL NEAR DEXTER, N. MEX.

Partial record of H. H. Sigman's well near Lake Arthur:[a]	Feet.
Soil and conglomerate	0– 5
Hard gypsum (first flow at base)	5– 130
Alternating strata of gypsum and red sand	130– 235
Alternating layers of red sand and clay	235– 345
White sand	345– 545
Red sand	545– 600

Partial list of artesian wells in Hagerman district.

Name of owner and location.	Depth.	Diameter.	Yield.[1]
	Feet.	*Inches.*	*Gallons (per minute).*
Calloway, E. H., T. 13 S., R. 26 E	454	.....	20
Carper, J. E., NW. ¼ NE. ¼ sec. 28, T. 12 S., R. 26 E	330	8	377
Casiers, T. M., NE. ¼ NW. ¼ sec. 7, T. 13 S., R. 26 E	400	6⅝	351
Clem, J. A., E. ½ sec. 11, T. 13 S., R. 26 E	525	7⅝	517
Criser, F. A., E. ½ NW. ¼ sec. 33, T. 12 S., R. 26 E	500	5⅝	300
Cummins, J. Q., SE. ¼ sec. 33, T. 12 S., R. 25 E	860	6⅝	250
Elliot, I. H	760	4½	.....
Formwault, SW. ¼ sec. 31, T. 12 S., R. 26 E	960	6⅝	848
Forstad, J., NE. ¼ sec. 13, T. 13 S., R. 26 E	664	7⅝	25
Geyer	300	5½	.....
Goodell, S. W., S. ½ sec. 15, T. 13 S., R. 25 E	830	8	.....
Greenfield farm (center), sec. 32, T. 13 S., R. 26 E	.....	5⅝	.....
Hagerman (town), NE. ¼ SE. ¼ sec. 10, T. 14 S., R. 26 E	760	8	.....
Hedgecoxe, NE. ¼ NE. ¼ sec. 18, T. 13 S., R. 26 E	960	6⅝	600
Lake Arthur, sec. 20, T. 15 S., R. 26 E	1,000	10	764
Large, Frank:			
Sec. 4, T. 13 S., R. 26 E	375	5⅝	420
Sec. 4, T. 13 S., R. 26 E	460	7⅝	599
Sec. 4, T. 13 S., R. 26 E	460	7⅝	599
Townsley, H. W.:			
NW. ¼ sec. 4, T. 13 S., R. 26 E	440	5⅝	.....
NW. ¼ sec. 4, T. 13 S., R. 26 E	450	5⅝	.....
Walters, L., SE. ¼ sec. 14, T. 13 S., R. 26 E	505	5⅝	310
Widdeman, NW. ¼ sec. 5, T. 13 S., R. 26 E	1,000	.....	.....
Wilson, P., NW. ¼ sec. 18, T. 13 S., R. 27 E	620	.....	20
Winchell, N. J., SE. ¼ SW. ¼ sec. 30, T. 13 S., R. 26 E	1,025	8	880

[1] Mainly estimated.

EDDY COUNTY.

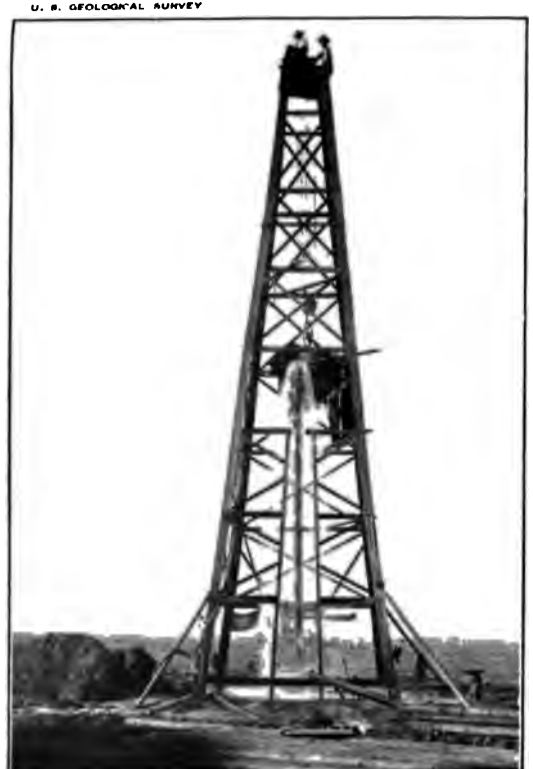
Artesia district.—The Artesia district comprises the northern portion of the area of flow included in Eddy County. The formations encountered in boring a deep well near Artesia differ somewhat from those in other parts of the Roswell basin. According to well records they consist for the first 500 to 700 feet of unconsolidated beds of sand, gravel, and clay, which by their loose texture frequently offer considerable difficulty in well construction. Beneath these beds there are alternating layers of red and gray sandstone, clay, and gypsum lying on a series of porous limestones, clays, and sandstones, in which the strongest artesian flows occur. A number of records of deep borings around Artesia, as reported by the well drillers, are here given:

[a] No satisfactory record, particularly of the lower part, could be obtained of this boring, which was originally 1,000 feet deep. There is probably some defect in the casing of the well, for, according to the latest reports, the lower part of the pipe appears to be clogging up with sediment, and there is a perceptible decrease in the pressure of the flow. The best information which could be obtained concerning the formations penetrated in the upper part of this well is here given.

Typical deep borings in Artesia district, New Mexico.

	F
Record of the J. C. Hale well, 1¼ miles southeast of Artesia:	
Soil	
Red clay	1
White, coarse sand	3
Fine sand	10
Bluish clay alternating with sandy layers	12
Red clay with layers of gravel	375
White sand	540
Yellow sand	550
Red, sandy clay	556
Limestone	581
Red, sandy clay alternating with layers of gravel	585
Gravel	745
Hard limestone	751
Limestone and red clay	760
Hard and soft light-colored limestone with layers of sandstone	794
Soft, red sandstone	820
Hard, porous limestone and red clay in alternate succession, the limestone predominating	830
Record of the J. S. Majors artesian well, 2 miles north of Artesia:	
Loamy soil	0
Bowlders	6
Concretionary conglomerate	15
Rock	40
Soft sands	62
Rocks and bowlders	68
Gray sand	70
Soft clay	72
Moderately hard rock	160
Red, sticky clay	174
Sticky clay and gravel	210
Coarse, white sand	240
Clay and gravel	275
Soft rock	290
Clay	295
Red quicksand	310
Red clay	320
Soft rock	357
Soft clay (First flow yielding about 10 gallons per minute)	360
Hard rock	420
Clay and gravel; some sand	428
Clay and sand	460
Soft rock and clay	542
Tough, red clay	560
Hard rock	598
Hard clay	600
Hard rock	617
Red clay	628
Soft rock	630
Hard rock	634
Sand and clay	640
Soft rock, clay, and sand	665
Quicksand	700
Hard rock (limestone; second flow at base)	704
Alternating strata of soft rock and clay	714
Soft and hard rock in alternate layers	770
Very hard rock (limestone)	79
Clay and soft rock	790
Extremely hard rock (limestone)	81
Rock, increasing in hardness	82
Record of the Hodges & Venable artesian well, Artesia: [a]	
Soil	
Bowlders and clay	10
Concrete rock	1

[a] In this well flows were obtained at the following depths: First flow, 450 feet; second flow, 648 *third flow*, 785 feet; fourth flow, 802 feet.



A. ARTESIAN TOWN WELL, AT ARTESIA, N. MEX.

B. SHERMAN'S PUMPING PLANT, NEAR ROSWELL, N. MEX.

Record of the Hodges & Venable artesian well, Artesia—Continued.	Feet.
Loose gravel	26 - 41
Concrete rock	41 - 46
Red clay	46 - 73
Concretionary gravel	73 - 76
Loose gravel	76 - 86
Hard limestone	86 - 113
Loose gravel containing water	113 - 120
Limestone	120 - 130
Red clay	130 - 155
Red clay alternating with conglomerate	155 - 185
Alternating strata of concretionary conglomerate and red clay	185 - 250
Red clay	250 - 350
Alternating layers of red, sandy clay and sandstone	350 - 545
Limestone, with an occasional layer of red clay, very hard at base of series	545 - 840
Record of the J. B. Barnes artesian well, 12 miles southwest of Artesia:	
Soil	0 - 6
Bowlders and gravel	6 - 13
Yellow clay and gravel	13 - 53
Red clay	53 - 153
Quicksand	153 - 157
Red sand and soft sandstone	157 - 177
Soft, yellowish sandstone	177 - 227
Hard limestone	227 - 267
Red, sandy clay alternating with soft red sandstone, which gives place to porous limestone in the lower half of the series. (First flow)	267 - 450
Soft, red sandstone	450 - 500
Porous limestone	500 - 525
Soft, red sandstone	525 - 535
Record of the S. L. Roberts artesian well, at Artesia:	
Soil	0 - 7
Bowlders and gravel	7 - 42
Red, sandy clay containing some gravel	42 - 200
Quicksand	200 - 260
Red clay	260 - 300
Alternating layers of gray sand and red clay	300 - 600
Limestone	600 - 604
Gypsum	604 - 634
Red clay	634 - 675
Limestone	675 - 679
Red clay	679 - 704
Limestone	704 - 705½
Red, sandy clay	705½ - 745½
Limestone	745½ - 840
Hard limestone	840 - 852
Red, sandy clay	852 - 880
Limestone, porous	880 - 976
Record of the E. N. Heath artesian well, 2 miles southwest of Artesia:	
Soil and clay	0 - 15
Gravel	15 - 30
Yellow clay	30 - 80
Gravel and sand	80 - 280
Sand	280 - 310
Gravel and sand	310 - 340
Hard, red clay	340 - 344
Gypsum	344 - 346
Conglomerate	346 - 366
Sand with thin streaks of gravel	366 - 441
Coarse-grained, porous rock	441 - 461
Gray sand	461 - 481
Red quicksand	481 - 631
Rock	631 - 641
Red quicksand	641 - 691
Hard, gray limestone	691 - 715
Red sand rock with streaks of clay	715 - 725
Gray limestone, very hard	725 - 745

Record of the W. E. Clark artesian well, 4 miles north of Artesia:

	Feet.
Soil	0- 6
Bowlders and gravel	6- 16
Gypsum	16- 76
Gravel	76- 81
Gypsum	81- 90
Concretionary conglomerate	90- 96
Hard gray sandstone	96-108
Red clay streaked with white clay	108-126
Dark-gray sandstone	126-157
Yellow sand	157-200
Hard gray sandstone	200-218
Red sand	218-222
Very hard light-gray sandstone	222-244
Red sand	244-247
Hard red rock	247-250
Red sand	250-268
Hard red rock	268-274
Alternating strata of quicksand and soft red sandstone	274-536
(In this series at 385 feet occurs the first flow; second flow at 475 feet.)	
Very hard limestone	536-540
Red sandstone, medium hardness	540-580

The greatest development in well sinking in this district is around Artesia, where a number of strong artesian flows have been obtained at depths of 800 to 1,000 feet. A partial list of these wells, including their location, depth, and size, is given in the following table:

Partial list of artesian wells in Artesia district.

Name of owner and location.	Depth.	Diameter.	Yield.[a]
	Feet.	*Inches.*	*Galls. per minute.*
Artesia (town), NE. ¼ NE. ¼ sec. 17, T. 17 S., R. 26 E.[b]	771	6	.....
Barnes, J. B., NW. ¼ NW. ¼ sec. 23, T. 18 S., R. 25 E	535	6	1,548
Bruce, J. A., NE. ¼ NE. ¼ sec. 14, T. 17 S., R. 26 E	872	5¾	562
C. A. P. Cattle Co., SW. ¼ NE. ¼ sec. 23, T. 17 S., R. 26 E	830	.....	.....
Clark, W. E.[c]	580	.....	.....
Deiss, J. J., sec. 32, T. 18 S., R. 26 E	570	6	.....
Gilberts, S. W., SW. ¼ sec. 7, T. 18 S., R. 26 E	813	6	320
Gilliland, J. W., SE. ¼ sec. 9, T. 18 S., R. 26 E.[d]	826	6	.....
Hale, J. C., NW. ¼ SE. ¼ sec. 15, T. 17 S., R. 26 E	850	6	1,162
Harris, N. T., SW. ¼ SW. ¼ sec. 14, T. 16 S., R. 26 E.[c]	.....	.....	.....
Heath, E. N., SE. ¼ sec. 18, T. 17 S., R. 26 E	746	6¾	.....
Hodges & Venable, SE. ¼ NW. ¼ sec. 23, T. 18 S., R. 25 E	840	6	1,110
Majors, J. S., SW. ¼ SW. ¼ sec. 31, T. 17 S., R. 26 E	823	.....	.....
Miller, L. C., SW. ¼ SW. ¼ sec. 8, T. 18 S., R. 26 E	671	6	1,04[illegible]
Norfleet, A. L., S. ½ NW. ¼ sec. 32, T. 17 S., R. 26 E	.....	.....	.....
Rawl & Robertson, sec. 5, T. 17 S., R. 26 E	650	.....	.....
Richey, John, SW. ¼ SW. ¼ sec. 11, T. 16 S., R. 26 E.[b]	835	.....	.....
Roberts, S. L., SE. ¼ SW. ¼ sec. 8, T. 17 S., R. 26 E	976	.....	.....
Smith, J. Mack, SW. ¼ NW. ¼ sec. 29, T. 17 S., R. 26 E	747	6¾	1,7[illegible]
Smith & Beckman, sec. 17, T. 17 S., R. 26 E	881	.....	.....
Stanford, L. G., NE. ¼ sec. 34, T. 18 S., R. 26 E	797	6	.....
Walterschied, W. M., E. ½ SW. ¼ sec. 8, T. 17 S., R. 26 E	795	6	.....

[a] Mainly estimated. [b] 92½ pounds pressure. [c] Incomplete. [d] 72½ pounds pressure.

McMillan district.—This district includes the area in the vicinity of McMillan and t valleys of North and South forks of Seven Rivers. Near McMillan the Walters & Shav and the Lakewood Townsite companies' wells have strong flows from the porous limest at depths of about 800 feet. The records of these wells indicate that the unconsolidat

sediments are about 250 feet thick and that the limestone division occurs 500 to 600 feet below the surface. The records of these wells were supplied by the drillers as follows:

Typical deep borings in McMillan district, New Mexico.

	Feet.
Record of the Walters & Shavers artesian well at McMillan:	
Soil	0- 6
Coarse gravel	6- 13
White clay	13- 33
Coarse sand and gravel containing water	33- 43
White chalky rock	43- 70
Very hard gray sandstone with layers of gravel	70-170
Hard flinty rock	170-177
Red clay and coarse gravel in alternate succession	177-235
Light-colored sandy clay	235-250
Red clay	250-254
Alternating strata of gypsum and red clay	254-370
Hard gypsum	370-393
Series of gypsum alternating with red clay	393-440
Alternating layers of white gypsum and red sandstone	440-500
Red sand and hard sandstone in alternate layers 2 feet thick	500-650
Hard white limestone	650-800
Extra hard limestone	800-820
White limestone becoming softer. (Flow of about 300 gallons)	820-845
Record of the Lakewood Townsite Company artesian well at McMillan:	
Loam and gravel	0- 49
Soft gypsum in strata 5 to 6 feet thick	49- 80
White chalky rock	80-120
Sandstone and gypsum in alternating layers	120-135
Pure white gypsum, moderately hard	135-200
Very hard white gypsum	200-450
Soft rock resembling shale	450-490
Alternating layers of hard and soft white rock containing a few thin layers of sandstone. (First flow at 770 feet, second flow at 810 feet)	490-863
Very soft, white rock	863-877
Alternating layers of soft and hard limestone	877-880

In Seven Rivers Valley wells are generally shallow, ranging in depth from 150 to 300 feet, and the flows so far have been obtained from the unconsolidated rock. It is probable, however, that wells sunk to a sufficient depth in this region would obtain flows from the limestone division. A partial list of the wells in the McMillan district is given in the following table, and their location is shown on Pl. VI:

Partial list of artesian wells in McMillan district.

Name of owner and location.	Depth.	Diameter.	Yield.
	Feet.	*Inches.*	*Galls. per minute.*
Brogden, J. C.:			
SE. ¼ SE. ¼ sec. 15, T. 20 S., R. 25 E	305	5⅝	573
Sec. 21, T. 20 S., R. 25 E	150?	5⅝	253
Boyd, G. M., SE. ¼ sec. 26, T. 19 S., R. 25 E	549	5⅝	.....
Cole, SE. ¼ sec. 7, T. 20 S., R. 25 E	195	6	.....
Eatons	400	.....	.....
Hellyer, W. E	190	6	12
Lakewood Townsite Co., sec. 27, T. 19 S., R. 26 E	885	6	.....
McDonald:			
NW. ¼ sec. 8, T. 20 S., R. 25 E	146	5⅝	75
NW. ¼ sec. 8, T. 20 S., R. 25 E	150	5⅝	.....
Plott, J. C., S. ½ NE. ¼ sec. 26, T. 19 S., R. 25 E	347	5⅝	.....
Walters & Shavers, NW. ¼ NW. ¼ sec. 23, T. 19 S., R. 26 E	845	6	300

PRESSURE OF ARTESIAN WATER.

In connection with the investigation of the geology and underground water relations of the Roswell basin a systematic measurement of well pressures has been carried on. At the time when this investigation was proposed there appeared to be no evidence that the flow was decreasing, but it was feared that the multiplicity of wells within such a limited area would eventually lower the water plane unless greater economy was practiced by the water users. In arranging for the testing and comparison of pressures a number of representative wells were selected at different points throughout the basin, four from Roswell, where many have been sunk in a relatively small area, and others from near Hagerman and Artesia. In making these selections care was exercised to obtain only those which were believed to be representatives of local districts and in perfect condition. In a few instances, however, defective pipes were discovered after the first monthly pressure had been recorded. Careful measurements were taken of these wells each month under uniform conditions so far as possible. The result of this investigation extending over a period of twelve months is shown in the following table:

Record of periodic pressure measurements in pounds per square inch, of artesian wells in the Roswell artesian basin, New Mexico, for year ending May 31, 1905. [a]

No.	Name and location.	June.	July.	August.	September	October.	November	January.	February.	March.	April.	May.	Total loss or gain.
	ARTESIA DISTRICT.												
1	Gilliland, [b] SW. cor. SE. ¼ sec. 19, T. 18 S., R. 26 E.	83	82	80	79	80	79	74	74	72½	69	69	−14
2	Hale, [c] NW. ¼ SE. ¼ sec. 15, T. 17 S., R. 26 E.	88	87	87	84	84	82	80	81	77½	77½	77½	−10½
3	Hodges & Venable, [b] middle of west line SE. ¼ NW. ¼ sec. 23, T. 18 S., R. 25 E.	31½	31½	30½	30	29	27	25	25½	24	21	21	−10½
4	Norfleet, [b] NW. cor. of S. ½ NW. ¼ sec. 32, T. 17 S., R. 26 E.	....	....	62½	61	61	58	55	56	54½	53	53	− 9½
5	Richey, [b] SW. ¼ NE. ¼ sec. 14, T. 16 S., R. 26 E.	....	....	....	....	....	95½	92	94	92½	91	91	− 4½
	HAGERMAN DISTRICT.												
6	Greenfield farm, [d] sec. 32 (center), T. 13 S., R. 26 E.	58	58	57	57	55	53½	53	53	54	....	....	....
7	Sigman, H. H., [b] NW. ¼ sec. 20, T. 15 S., R. 26 E.	....	....	....	....	....	41	33	30½	....	25	27	−14
8	Widdeman, A. J., [b] SW. ¼ SW. ¼ sec. 5, T. 13 S., R. 26 E.	....	40	40	40	38	41	41½	39½	39	39	39	− 1
	ROSWELL DISTRICT.												
9	Hagerman, J. J., [b] near center of west line NW. ¼ SE. ¼ sec. 13, T. 11 S., R. 24 E.	13	13	13	13½	13½	13½	13½	13½	14	13½	13½	+ ½
10	Hamilton, [b] lot 12, block 14 (original townsite), SW. ¼ SW. ¼ sec. 33, T. 10 S., R. 24 E.	6¾	6¾	7¾	7	7	7¾	7	7¾	8	8	8	+ 1¼
11	McClenny, [e] SE. ¼ SE. ¼ sec. 35, T. 10 S., R. 24 E.	16¾	16¾	20	20	20	21	20	21½	22	21½	21½	+ 4¾
12	Parsons, [b] lot 4, block 54 (west side), NE. ¼ SE. ¼ sec. 32, T. 10 S., R. 24 E.	7	7	7	7	7	7	7	7½	8	8	8	+ 1
13	P. V. and N. E. roundhouse, [f] NE. cor. NW. ¼ SW. ¼ sec. 33, T. 10 S., R. 24 E.	12	10	10	12	12	12	12	13	13	13	13	+
14	Rasmussen, [b] SW. ¼ NW. ¼ sec. 21, T. 11 S. 25 E.	31	31	31	31	31	32½	33	31	31½	31½	31½	+
15	Yater, [b] lot 7, block 26 (original townsite), NE. ¼ SE. ¼ sec. 32, T. 10 S., R. 24 E.	7	7	7	7	7	7	7	7	10	....	10	+

[a] No measurements were obtained for December.
[b] Casings of Nos. 1, 4, 5, 7, 9, 10, 12, 14, and 15 were in perfect condition, or apparently so; slight leakage at valve of Nos. 1, 3, and 8.
[c] Decrease in pressure may be due to escape of water into a higher artesian horizon, which is reached by a shallow well not far away.
[d] This is an old well and the casing may be defective.
[e] Low pressures in the months of June and July due to leakage in pipe.
[f] Slight leakage in casing near surface and at valve caused a decrease of pressure in July and August measurements.

In most cases in the Roswell and Hagerman districts, where the wells were in perfect ndition, the pressures of the flows appear to be substantially accordant, but around tesia there are several wells in which the flows have materially decreased in pressure ring the last twelve months. Without a thorough knowledge of the conditions under ich artesian water is obtained around Artesia the decrease in pressure of some of the ongest flows in that vicinity might at first appear alarming, but a comparison of this strict with that of Roswell, where there is no decrease in pressure, introduces many portant factors which have a direct bearing on the case.

At Roswell artesian water is obtained at a depth of about 250 feet, and the materials ssed through offer practically no difficulty; as a result, very perfect wells are constructed. hen, too, in this region wells have been built for the last decade, and the well driller so familiar with the conditions that he can predict with a fair degree of accuracy the aterials to be encountered in sinking a well. Farther south in the basin, in the vicinity Artesia, a successful artesian well is not so easily obtained. Here the main flow is ached at much greater depths, which range from 700 to 900 feet, depending on the loca-on. The increased depth is due to the presence of beds overlying the porous limestone eries. They consist of red sand and gypsum of the supposed Permian series, and clay, ne sand, and gravel of the unconsolidated deposits. The sands predominate throughout nd have often a loose texture familiarly known to the well driller as quicksand. This naterial is very difficult to drill through because of caving, and in one or two instances t was so troublesome that the owner was compelled to abandon the project. The pressure at the surface in an average well around Artesia is about 80 pounds to the square nch, which means over 400 pounds to the square inch at the bottom of a well 800 feet leep. Such forces are difficult to manage, particularly where exploitation in the region has not been sufficiently extensive to enable the well driller to thoroughly acquaint himself with the nature of the obstacles to be encountered, and make suitable provision for them. The region is also one that offers considerable inducement to the ambitious well driller. As a result, new machines are constantly coming into this field, and the operators, though skilled in the art of well drilling, are entirely unfamiliar with this locality. It can readily be seen that under these circumstances imperfect wells are likely to result. Some of the strongest flows in the basin are and have been unmanageable since their completion, while others owing to unfavorable conditions are not working satisfactorily.

COMPOSITION OF ARTESIAN WATERS.

General statements.—The artesian waters of the Roswell basin are all more or less mineralized, but in only a few cases are the mineral constituents present in sufficient amounts to materially affect the taste or to be deleterious to plant growth. An average sample of the waters of North and South Spring rivers contains 75 parts of soluble matter to 100,000 parts of water. About two-thirds of the total solids consists of calcium carbonate and calcium sulphate, which are regarded as harmless to plants. The more soluble ingredients of the water, consisting of sodium chloride, magnesium sulphate, and potassium sulphate, occur in amounts too small to injure plant growth if the ground is properly

drained. The following analyses of waters of North and South Spring rivers were made by Prof. E. M. Skeats, of El Paso, Tex.:

Analyses of water from springs in North Spring and South Spring rivers.

SAMPLES FROM MARGINAL SPRINGS IN NORTH SPRING RIVER.

[Parts per million.]

	Total solids.	Silica (SiO_2).	Water.	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Chlorine (Cl).	Sulphuric acid (SO_4).	Carbonic acid (CO_2).
No. 1	820	15	84.7	122.3	46.8	57.5	93.6	281.9	118.1
No. 2	710	20	96.9	146.6	48.8	8.5	56.4	240.6	116.9
No. 3	700	25.1	65	106.2	45.4	37.5	78.9	242.1	102.0
No. 4	635.6	15	.....	126.0	43.5	22.5	67.9	245.6	115.1
No. 5	610	20	14.1	102.2	43.4	30.3	49.6	245.5	104.9
Mean	699.1	19	52.1	120.7	45.6	31.2	69.3	251.5	111.4

SAMPLES FROM MARGINAL SPRINGS IN SOUTH SPRING RIVER.

[Parts per million.]

	Total solids.	Silica (SiO_2).	Water.	Calcium (Ca).	Sodium (Na).	Chlorine (Cl).	Carbonic acid (CO_2).	Calcium magnesium sulphate.
No. 1	700	26.9	49.4	80.9	23.5	46.7	121.6	351
No. 2	730	30.8	50.0	72.1	51.0	63.0	107.9	355.2
No. 3	690	22.3	53.0	76.1	16.8	27.9	114.9	378
No. 4	790	16.0	63.4	72.1	32.1	48.5	107.9	450
No. 5	1,140	50.0	94.0	80.1	62.1	63.7	119.9	670
No. 6	1,070	41.5	85.5	80.1	52.8	81.2	119.9	609
Mean	853.3	31.2	65.9	92.3	44.7	66.2	115.4	468.9

SAMPLES FROM BOTTOM SPRINGS IN SOUTH SPRING RIVER.

	Total solids.	Silica.	Water.	Ca.	CO_2.	Na.	Cl.	Calcium magnesium sulphate.
No. 1	680	27.2	51.8	111	74	18.9	29.1	368.0
No. 2	650	13.4	51.2	106.2	70.8	17.1	26.3	365
No. 3	700	9.6	57.0	106.2	70.8	19.9	30.5	406
No. 4	670	20.5	52.5	106.2	70.8	18.7	28.8	372.5
No. 5	620.8	.....	27.8	109.2	72.8	17.3	26.7	367
No. 6	700	50.2	55.0	106.8	71.2	16.9	25.9	374
No. 7	690	38.3	55.0	106.2	70.8	18.0	27.7	374
No. 8	700	41.6	53.9	105.6	70.4	17.5	27.0	384
No. 9	690	45.0	51.0	112.5	75.0	17.5	27.0	362
Mean	678	27.4	50.5	107.8	71.8	18.0	27.7	374

The composition of the artesian water at Roswell differs somewhat from that of North Spring River. The total solids are greater and also the amount of sodium chloride. The following analysis will show the composition of the water from a number of representative wells at Roswell.

Analyses of water from artesian wells at Roswell.

[Individual data. Parts per million.]

Name and date.	Depth.	Temperature.	Total solids.	Silica.	Ca.	CO_3.	Mg.	Na.	Cl.	Calcium magnesium sulphate.
Crowley:	*Feet.*	° *F.*								
April, 1896	155	64.5	1130	48.0	76.1	113.9	.....	160.9	247.6	483.5
April, 1897	155	64.5	930	69.5	70.1	94.9	.....	114.5	176.0	395.0
Matthews, Tenn., south of	192	69	680	86.5	56.1	83.9	.....	44.7	68.8	340.0
Cahoon:										
1895	227	70.5	860	91.0	76.1	113.9	.....	92.2	141.8	315.0
1896	227	70.5	790	35.5	71.1	106.4	3.9	96.5	108.0	316.6
Poe, J. W	237	69	930	46.0	76.1	113.9	.....	89.8	138.2	466.0
Judge Lea	225	71	810	20.2	76.9	115.1	.....	86.6	133.2	378.0
Captain Clark	256	69.25	1,330	123.0	70.1	94.9	.....	154.1	236.9	641.0
Miller, H. M	230	.....	1,020	72.3	63.1	106.4	5.67	111.5	171.5	487.5
Prager	218	.....	1,170	92.8	73.8	110.4	.....	106.0	163.0	576.5
Steam laundry	.....	.....	1,290	182.0	68.0	102.0	.....	183.6	282.4	472.0
Lea, J. C	331	.....	1,160	33.0	70.1	94.9	.....	150.0	230.0	572.0

The waters of the larger tributaries of Pecos River from the west, analyzed by Prof. E. M. Skeats, are reported to have the following composition:

Analyses of water of the Hondo, Felix, North and South forks of Seven Rivers, and Penasco rivers.

River and location.	Total solids.	Silica, etc., plus water.	Ca.	Mg.	Na.	CO_3.	SO_4.	Cl.	Temperature.	Remarks.
									° *F.*	
Hondo (above Pleacho).	1,195	80.7	231.9	59.1	37.1	104.3	622.4	59.5	.....	Water fairly clear.
Felix (head spring)	467.2	18.8	107.9	23.9	15.2	125.0	152.0	23.3	64	
South Seven (head spring).	1,320.0	194.9	231.7	74.7	13.8	112.4	670.9	21.3	66.5	
North Seven (head spring).	1,020.0	75.6	164.0	71.8	38.9	102.2	567.7	19.8	.....	
Penasco (by Gilberts)	650.0	10.0	136.7	42.8	15.2	107.9	324.3	23.3	.....	Trace of hydrogen sulphide.

ORIGIN OF THE ARTESIAN WATER.

The water-bearing formations in the Roswell artesian area outcrop in successive zones on the higher slopes to the west. There they receive their water supply by direct absorption from rainfall and by the sinking of streams (see Pl. IX). The Hondo, Felix, Penasco, and Seven rivers are the most important sources. These streams all rise high on the slopes of the Capitan, Sierra Blanca, and Sacramento mountains, where the rainfall is relatively large. As a result they carry an abundance of water in their upper courses, all of which sinks in the outcrop zone of the porous limestones and the overlying formations and passes underground to the east. After the water has entered these porous formations it is confined by impervious layers of limestone or clay, and under the lower lands to the east it is under considerable *pressure*.

AMOUNT OF ARTESIAN WATER.

It is difficult to make even an approximate estimate of the total amount of artesia water available in the porous formations underlying the Roswell artesian area. We do not know definitely how much water is absorbed by the permeable rocks in their western outcrop, and we are unable to calculate the amount which escapes through springs and by underflow along Pecos River.

The area drained by the larger western tributaries of Pecos River comprises in all about 4,000 square miles. It lies along the east slopes of the Capitan, Sierra Blanca, and Sacramento mountains. The location and extent of the combined watersheds of all stream supplying water to the underlying formations of the Roswell basin is shown in Pl. IX. Th annual precipitation for this general region is comparatively large, ranging from 10 to inches. The mean annual precipitation at Fort Stanton, N. Mex., which lies in the ar drained by Hondo River, is about 15 inches. The average for seventeen years prior 1891 was 19 inches, but from 1901 to 1903, inclusive, the annual rainfall was far bel the average. The following table shows the result of observations through a period nearly five years, ending with 1904:

Monthly and annual precipitation, in inches, at Fort Stanton, N. Mex.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	A nu
1900	.....	.....	0.48	0.90	1.09	1.63	1.98	2.18	6.06	1.43	0.40	0.36	...
1901	0.10	.....	.....	0.90	0.64	1.34	.....	1.85	2.00	1.76	2.85	0.95	...
1902	0.05	0.38	0.22	0.00	1.88	0.24	2.28	1.87	0.48	1.81	0.16	0.57	9
1903	0.36	0.75	0.17	0.20	0.38	3.41	0.62	1.55	1.55	0.48	0.00	0.05	9
1904	0.02	0.10	0.03	0.15	0.14	.....	2.87	2.92	6.06	2.68	0.08	0.35	...

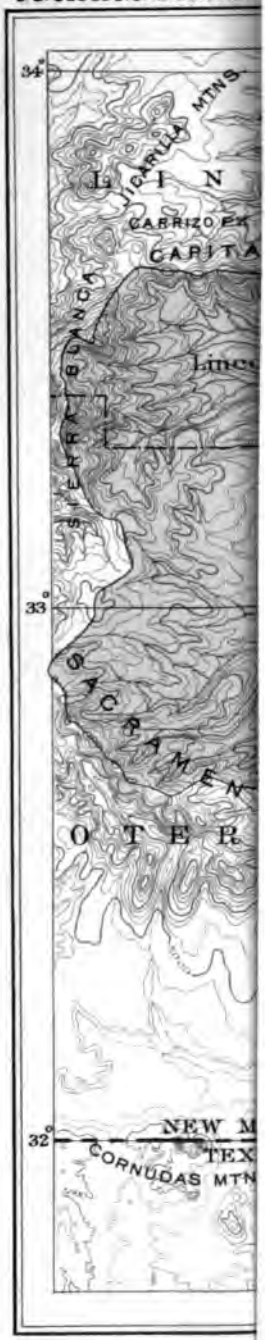
At Lower Penasco, situated on the headwaters of Penasco River, the mean annual p cipitation is about 18 inches, as is shown by the following table:

Monthly and annual precipitation, in inches, at Lower Penasco, N. Mex.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	A nu
1896	0.80	0.40	0.10	T.	T.	2.05	3.56	1.38	1.57	6.01	T.	0.40	1
1897	1.40	T.	.....	0.50	0.85	0.55	5.60	3.15	1.80	1.05	0.10	0.25	...
1898	0.60	0.25	0.10	1.65	0.70	1.80	7.40	4.00	1.15	T.	0.30	2.40	2
1899	T.	0.20	0.35	T.	0	1.70	5.89	1.35	2.90	1.15	1.50	1.05	1
1900	0.90	0.30	0.35	0.30	1.70	2.60	4.85	1.95	5.45	1.05	T.	0.60	2
1901	.....	.....	.....	0.50	1.15	1.05	6.68	0.97	3.90	.....	.....	T.	...
1902	0.80	0.05	0.00	T.	0.35	0.30	.....	.....	.....	.....	.....	.....	

From the above statements it is apparent that the total amount of water which falls du a year of average precipitation throughout the combined watershed of the Hondo, F Penasco, and Seven rivers is necessarily large. Of course a portion of this water is los evaporation and run-off, but a considerable amount is absorbed by the water-bearing r and becomes available to the east as artesian water. It has not been practicable in present investigation to compute the total outflow of all the artesian wells in the Ros basin, but at a liberal estimate this amount would probably be only a small proportio the quantity absorbed by the water-bearing rocks throughout their western outcrop a This is clearly shown by the large number of wells which it has been possible to sink in town of Roswell without materially diminishing the flows of some of the first wells dug. is possible that the amount of artesian water available around Artesia is not so great a

U. S. GEOLOGICAL SURVEY



MAP OF

SHOWING TH

Roswell, but the only evidence of this is the decrease in pressure of some of the wells at Artesia. The combined watershed of the streams lying west of this part of the basin is larger than that of Hondo River, and according to the Weather Bureau records it has a somewhat greater annual rainfall. For these reasons we would expect the formations underlying the southern part of the basin to contain a large amount of water. While there is evidence of a general decrease in flow throughout the Artesia district, it is probable that this diminution is largely due to the clogging of the pipes with sediment, the escape of water along the outside of the tubing from lower to higher horizons, and various other causes which are known to affect the flow of artesian wells.

It is believed that there is no cause for fear that the water supply throughout the northern part of the Roswell basin will give out or become inadequate for all requirements under proper economy of practice. In the region of Artesia and McMillan not enough wells have been sunk to indicate the amount that the water-bearing beds may be expected to yield.

WASTE OF WATER.

There is pressing need for greater econony on the part of the users of well water throughout the Roswell basin. At Roswell a city ordinance regulates the management of all flowing wells, but throughout the remainder of the district no restraint whatever is placed upon the management of the wells, and, with very few exceptions, they are allowed to flow continuously. A small portion of this water is stored in artificial reservoirs, but by far the greater part runs off into pools, evaporates and seeps away on uncultivated lands, or runs directly into Pecos River. In one case noted a ditch leads from the well directly to the river, a distance of one-half mile, and it is not an unusual thing to find water flowing from the wells to low, marshy lands adjacent to the river, where by underflow it soon reaches the main channel. Formerly many of the wells were not even furnished with reservoirs, and the water was carried by laterals directly to the fields during the irrigating season, and at other times was allowed to flow off through wasteways.

Nearly all the wells that are being constructed at the present time in the southern part of the basin are to be furnished with reservoirs ranging in capacities from 6 to 24 acre-feet, which are filled as often as necessary during the irrigating season. Even these commendable provisions are quite ineffectual in the case of wells not provided with valves, as they conserve only a relatively small portion of the total flow. An effort is now being made by a few of the well owners in the vicinity of Artesia to provide each well with a suitable valve, so that, when the water is not in use and the reservoir is full, the flow can be shut down. There is a general prejudice among well owners against shutting off the flow, as they fear that it will decrease the efficiency of the well. It is true that in a few cases wells have been damaged in this way, but where they were properly constructed the per cent injured is very small.

SHALLOW WELLS.

More or less water is obtained throughout the Roswell basin at depths varying from 25 to 200 feet. The water usually occurs in coarse gravel of the unconsolidated deposits. The supply appears to be inexhaustible, and in many cases the water is used for irrigation purposes. Outside the area of flow from Roswell to Hagerman there are a number of wells 75 to 100 feet deep, which furnish 5,000 to 7,000 gallons of water a day. The water is generally pumped with windmills. In the vicinity of Roswell a few deep nonflowing wells are provided with gasoline engines. A gasoline pumping plant on Sherman's farm, at Roswell, is shown in Pl. VIII, *B*.

Bordering the area of flows throughout the Roswell basin there is a zone of irrigable land 3 to 5 miles wide, in which water would probably rise in deep wells to within 100 feet of the surface, so that it could be profitably pumped for irrigation. The approximate limits of this area are shown on Pl. VI.

The following list gives the principal features of a number of shallow wells in the nortl part of the Roswell basin:

List of shallow wells in the Roswell basin.

Name of owner and location.	Depth.	Am pun per
	Feet.	*Gal*
Albrecht, E. O., NW. ¼ sec. 32, T. 12 S., R. 25 E	88	.....
Altebery, J. R., S. ½ NW. ¼ sec. 28, T. 11 S., R. 23 E	208	.....
Bethel, H., W. ½ NW. ¼ sec. 1, T. 17 S., R. 25 E	72	.....
Bowers, J. S., SW. ¼ sec. 23, T. 11 S., R. 23 E	132	
Brink, F., E. ½ NW. ¼ sec. 15, T. 11 S., R. 23 E	125	
Clark, J. H.:		
NW. ¼ sec. 18, T. 17 S., R. 26 E	38	.....
SE. ¼ SE. ¼ sec. 12, T. 17 S., R. 25 E	100	.....
Com, W. W., SW. ¼ SW. ¼ sec. 35, T. 11 S., R. 25 E	42	.....
Costa, N., SE. ¼ SE. ¼ sec. 8, T. 11 S., R. 24 E	27	
Gilbert, C. H., NE. ¼ NE. ¼ sec. 21, T. 11 S., R. 25 E	360	.....
Gishwiller, J. A., SW. ¼ sec. 18, T. 11 S., R. 24 E	71	
Hobbs, J. W.	58	.....
Hobbs & Hanney, SE. ¼ sec. 2, T. 11 S., R. 23 E	77	
Hortenstein, SW. ¼ sec. 23, T. 12 S., R. 25 E	102	
Miller, F., T. 11 S., R. 23 E	85	
Millheiser, P.:		
SW. ¼ SW. ¼ sec. 7, T. 11 S., R. 24 E	30	
SW. ¼ NE. ¼ sec. 7, T. 11 S., R. 24 E	175	
Paulson, P. O., NW. ¼ sec. 30, T. 13 S., R. 26 E	58	.....
Peck, J. C., SE. ¼ sec. 27, T. 11 S., R. 23 E	160	
St. John, J. A., SE. ¼ SE. ¼ sec. 18, T. 11 S., R. 24 E	60	
Saunders, J. P., SW. ¼ NW. ¼ sec. 8, T. 13 S., R. 25 E	155	.....
Smith, E. L., T. 11 S., R. 23 E	129	
Stockard, J. W.:		
SE. ¼ SE. ¼ sec. 23, T. 11 S., R. 23 E	150	
NW. ¼ SE. ¼ sec. 23, T. 11 S., R. 23 E	92	
Turner, W. P., NE. ¼ NE. ¼ sec. 7, T. 11 S., R. 24 E	30	
White, G. A., sec. 18, T. 14 S., R. 26 E	84	.....
Williams, O. L., NE. ¼ sec. 7, T. 12 S., R. 25 E	103	.....

IRRIGATION.

Irrigation has been practiced to some extent in the Roswell basin since the first se ments were made, but prior to 1889 only a few small farms were irrigated. The pe nent water supply in the vicinity of Roswell was the first to be utilized. Here a nu of small ditches were dug, and by extending these ditches from time to time the pr Roswell irrigation system has been developed. The Northern canal system, which gates the territory south of Roswell, was built by a development company as a pa a large irrigating project, designed to irrigate Pecos Valley from Roswell to the T New Mexico line.

Roswell system.—A number of ditches have been constructed from the head sprin Middle and South Berrendo and North and South Spring rivers, which furnish wat the land along their valleys. The surplus water of these ditches is directed into the N ern canal to be used for irrigation farther down Pecos Valley.

Northern canal.—This canal extends from Hondo River at a point about 5 miles e Roswell to near Lake Arthur, a distance of about 35 miles, and irrigates a large di of well-improved farming land in the vicinity of Hagerman. Besides receiving water

ie Berrendo and North and South Spring rivers, the Northern canal is supplied with ater to some extent by artesian wells. Though the water of the Northern canal is highly ineralized from the large amount of seepage water which it receives in the vicinity of oswell, the harmful salts apparently are not present in sufficient quantities to affect plant owth. The following analysis made by Prof. E. M. Skeats shows the average condition the Northern canal water:

Analysis of Northern canal water.

	Parts per million.
dium (Na)	256.1
dium and potassium sulphates	230.0
gnesium (Mg)	50.4
lcium (Ca)	428.0
lorine (Cl)	393.9
rbonic acid (CO_2)	101.9
lphuric acid (SO_4)	349.7
ica, alumina, and iron ($SiO_2Fe_2O_3Al_2O_3$)	20.0
ater of crystallization	190.0
Total solid	2,020.0

Hondo project.—Preparations are now being made by the Government to store the flood aters of Hondo River for the purpose of irrigating lands along Hondo Valley above Rosell. The location of the proposed reservoir is in a high natural depression on the divide tween Blackwater Arroyo and Hondo River. The surface rock in the vicinity is a masre blue limestone, weathering to light gray, underlain by alternate layers of gypsum d red and yellow clay. The bedding was originally uniform, but surface waters have solved the gypsum, causing a settling of the beds in the bottom of the reservoir and nsiderable local distortion around its rim. A number of borings were made with a diaond drill in the bottom of the reservoir, in order to determine the character of the undering rocks. The following is a record of one of these borings:

Record of diamond-drill boring, Hondo reservoir site, New Mexico.

	Feet.
ay	0 -11.1
roken limestone	11.1-22
ay	22 -25
vity	25 -30
roken rock cavities	30 -64.4
ypsum	64.4-70.2
ay	70.2-71.9
vity	71.9-73.4
oose rock	73.4-76.8
ypsum	76.8-79.8
ay	79.8-80.2
imestone	80.2-88.4
ypsum	88.4-91.8

ARTESIAN IRRIGATION.

The use of artesian water for irrigation in the Roswell area began soon after the first wing wells were obtained, and it has been gradually increasing ever since. Irrigation om the waters of Hondo and North and South Spring rivers has been practiced, as preously stated, for many years, and the use of artesian water was not resorted to until ost of the surface waters of the region had been appropriated. There are now several rms in the vicinity of Roswell that depend entirely on artesian water for irrigation, and the south nearly all the land included in the area of flow has been filed on with the tention of reclaiming it by artesian irrigation. Many of the farmers in the vicinity of oswell who have practiced artesian irrigation for several years have obtained results hich are highly satisfactory. This has caused considerable interest and enthusiasm among hose living farther south in the less developed portions of the basin, and in this region

many large wells are now being sunk, which will be used exclusively for irrigation. I of these wells are being provided with storage reservoirs, so that a larger amount of w will be available during the growing season.

Among many landowners throughout the area there is a tendency to overestimate amount of land that can be irrigated from an ordinary artesian well. According to servative estimates made by irrigators who have had considerable experience in this loc a flowing well with a yield of 450 gallons per minute, provided with a suitable storage r voir, will irrigate 30 acres of alfalfa or 70 acres of orchard. In order to accomplish this, l ever, the land must have the proper slope and the soil must be of uniform texture. Al requires more water than any of the staple crops. Under ordinary conditions 30 in per year is sufficient, but if the land is irrigated during the winter a larger quantity i quired. If this amount of water is properly applied, three or four crops may be cut harvesting period ranging from May to the latter part of August. An average yiel alfalfa is 1 ton to the acre for each cutting.

It is difficult to make definite statements regarding the irrigation of orchards in locality. It is accomplished in many different ways, depending mainly on the age condition of the trees. In many instances vegetables are raised between the rows of t and no additional water is required for the irrigation of the orchard. It is generally s cient to water an orchard once a month during the summer and once, or possibly not a during the winter. About 15 to 20 inches of water a year is required.

CLIMATE.

Temperature.—The climate of the Roswell basin does not differ materially in the vailing aridity from that of the remainder of southern and eastern New Mexico. The perature of the region is high, with a low relative humidity. The summers are usually and hot and the winters mild and pleasant. The maximum temperature is 110° an minimum seldom falls far below zero. The following tables compiled from the recor the United States Weather Bureau give the mean monthly maximum and minimum peratures of the Roswell district. The observations extend over a period of ten y 1895 to 1904, inclusive:

Mean monthly temperature at Roswell, N. Mex.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
Maximum	71.6	78.6	85.4	90.1	86.9	101.4	99.2	99.4	97.3	87.5	81.5
Minimum	6.5	5.4	18.4	26	38.5	49.9	56.8	55	41	28.5	17

Rainfall.—The average annual precipitation at Roswell is 16.6 inches. The gr part of this amount falls during the months of June and July in frequent showers, w although often violent, are generally local and of short duration. Only a small perce of the annual precipitation falls as snow. The following record of the monthly and a pecipitation at Roswell, extending over a period of ten years, shows considerable varia

Monthly and annual precipitation, in inches, at Roswell, N. Mex.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
.....	0.40	0.48	0.02	0.14	2.31	1.28	4.45	2.99	1.09	2.11	0.85	0.07	16.19
.....	0.60	0.14	0.02	T.	0.12	1.97	1.79	0.40	1.89	5.46	0	0.64	13.12
.....	1.12	0	0.59	1.35	3.76	1.42	2.78	2.94	1.25	.44	T.	T.	15.65
.....	0.26	0.86	T.	0.34	1.03	6.05	6.53	2.99	0.69	T.	0.50	1.37	20.62
.....	0.06	0.15	0.06	0.23	0.27	1.62	4.37	1.21	3.64	0.20	3.21	1.54	16.56
.....	0.96	T.	0.50	0.39	1.62	2.13	2.85	1.25	6.53	3.33	0.17	0.07	19.80
.....	0.21	1.15	0.00	0.97	1.04	0.22	3.04	0.60	1.99	2.21	6.15	0.26	17.84
.....	1.24	0.00	0.83	T.	0.70	1.03	5.52	1.80	3.08	1.36	0.52	0.50	16.58
.....	0.22	0.96	0.10	T.	0.74	4.37	.....	.....	0.92	T.	0.00	0.00	.....
.....	0.16	0.14	0.00	0.07	1.30	1.80	1.23	0.83	5.10	2.67	0.15	0.30	13.75

he heaviest rainfall ever recorded at Roswell was on October 31, 1901, when 5.65 inches in one night, causing considerable damage by flooding.

AGRICULTURE.

'he general aridity of the climate renders farming without irrigation impracticable ept in a few low-lying areas adjacent to Pecos River. In consequence agriculture is ricted to those portions of the valley where water can be obtained from some of the vari- canals or from artesian wells. The cultivated portions of the basin at present com- e about one-eighth of the total area included in this report, the remainder being utilized pasturage of cattle—an industry to which the higher lands are well adapted. The chief ducts are alfalfa, Kaffir corn, wheat, oats, corn, potatoes, Mexican beans, cantaloupes, ry, and a large variety of garden vegetables. Alfalfa and Kaffir corn are perhaps the gest crops and both are consumed in the region. Fruit raising is a growing industry and ny large orchards are found in the irrigated district. Peaches, pears, plums, cherries, l other small fruits have a hardy growth and an abundant yield, but the apple crop is most important. At South Spring there is a large apple orchard, comprising about 600 es, from which many thousand pounds of apples are shipped annually. Several large le orchards have been planted during the last five years, and fruit raising seems destined become one of the most important industries of the district. The seasons are ordinarily sufficient length to insure the maturity of all cultivated crops.

LASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 158.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress, for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at prices slightly above cost.
4. Copies of all Government publications are furnished to the principal public libraries in the large cities throughout the United States, where they may be consulted by those interested.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified in the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. This paper is the eighty-first in Series B, the twentieth in Series I, and the fifty-first in Series O, the compete lists of which follow (PP=Professional Paper; B=Bulletin; W-S=Water-Supply Paper):

SERIES B, DESCRIPTIVE GEOLOGY.

2. Observations on the junction between the Eastern sandstone and the Keweenaw series on Keweenaw Point, Lake Superior, by R. D. Irving and T. C. Chamberlin. 1885. 124 pp., 17 pls. (Out of stock.)
3. Notes on geology of northern California, by J. S. Diller. 1886. 23 pp. (Out of stock.)
9. The upper beaches and deltas of Glacial Lake Agassiz, by Warren Upham. 1887. 84 pp., 1 pl. (Out of stock.)
10. Changes in river courses in Washington Territory due to glaciation, by Bailey Willis. 1887. 10 pp., 4 pls. (Out of stock.)
15. The present condition of knowledge of the geology of Texas, by R. T. Hill. 1887. 94 pp. (Out of stock.)
16. The geology of Nantucket, by N. S. Shaler. 1889. 55 pp., 10 pls. (Out of stock.)
17. A geological reconnaissance in southwestern Kansas, by Robert Hay. 1890. 49 pp., 2 pls. (Out of stock.)
18. The glacial boundary in western Pennsylvania, Ohio, Kentucky, Indiana, and Illinois, by G. F. Wright, with introduction by T. C. Chamberlin. 1890. 112 pp., 8 pls. (Out of stock.)

B 67. The relations of the traps of the Newark system in the New Jersey region, by N. H. 1890. 82 pp. (Out of stock.)

B 104. Glaciation of the Yellowstone Valley north of the Park, by W. H. Weed. 1893. 41 pp. (Out of stock.)

B 108. A geological reconnaissance in central Washington, by I. C. Russell. 1893. 28 pp., (Out of stock.)

B 119. A geological reconnaissance in northwest Wyoming, by G. H. Eldridge. 1894. 72 pp., (Out of stock.)

B 137. The geology of the Fort Riley Military Reservation and vicinity, Kansas, by Robert Hay. 1896. 35 pp., 8 pls.

B 144. The moraines of the Missouri Coteau and their attendant deposits, by J. E. Todd. 1896. 71 pp., 21 pls.

B 158. The moraines of southeastern South Dakota and their attendant deposits, by J. E. Todd. 1899. 171 pp., 27 pls.

B 159. The geology of eastern Berkshire County, Massachusetts, by B. K. Emerson. 1899. 139 pp., 9 pls.

B 165. Contributions to the geology of Maine, by H. S. Williams and H. E. Gregory. 1900. 212 pp., 14 pls.

WS 70. Geology and water resources of the Patrick and Goshen Hole quadrangles in eastern Wyoming and western Nebraska, by G. I. Adams. 1902. 50 pp., 11 pls.

B 199. Geology and water resources of the Snake River Plains of Idaho, by I. C. Russell. 1902. 192 pp., 25 pls.

PP 1. Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska, by A. H. Brooks. 1902. 120 pp., 2 pls.

PP 2. Reconnaissance of the northwestern portion of Seward Peninsula, Alaska, by A. J. Collier. 1902. 70 pp., 11 pls.

PP 3. Geology and petrography of Crater Lake National Park, by J. S. Diller and H. B. Patton. 1902. 167 pp., 19 pls.

PP 10. Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen and Kowak rivers, by W. C. Mendenhall. 1902. 68 pp., 10 pls.

PP 11. Clays of the United States east of the Mississippi River, by Heinrich Ries. 1903. 298 pp., 9 pls.

PP 12. Geology of the Globe copper district, Arizona, by F. L. Ransome. 1903. 168 pp., 27 pls.

PP 13. Drainage modifications in southeastern Ohio and adjacent parts of West Virginia and Kentucky, by W. G. Tight. 1903. 111 pp., 17 pls.

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SUMMARY

OF THE

NDERGROUND-WATER RESOURCES OF MISSISSIPPI

BY

A. F. CRIDER and L. C. JOHNSON

WASHINGTON
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IMARY OF THE UNDERGROUND-WATER RESOURCES OF MISSISSIPPI.

By A. F. Crider and L. C. Johnson.

INTRODUCTION.

GENERAL WATER CONDITIONS IN MISSISSIPPI.

· problem of obtaining potable water in sufficient quantities and at a minimum cost ng engaged the attention of scientific and practical men in both Europe and America. recently the death of a large number of people from infectious diseases contracted inking contaminated surficial water has directed the attention of the general public · necessity of seeking drinking water from some other source.

the Gulf Coastal Plain, of which Mississippi is a part, conditions are favorable for ing to a minimum the death rate caused by drinking impure and unwholesome water. dy of the geologic conditions of the State shows that there is a great thickness of solidated sands interbedded with water-tight clays which dip slightly to the south 'est and form large underground reservoirs for the accumulation of water. The State heavy annual rainfall, which enters the upturned edges of the open-textured sands, :s in these wide reservoirs, and thus becomes available as well water when the over- strata are drilled through. Good deep-well water can be obtained over almost the State, and there are large areas in which under favorable conditions flowing wells ›tained. The dip of the strata is so regular and the water horizons are so numerous he areas are small in which potable water can not be found at comparatively shallow s.

nost of the localities having flowing wells the supply seems adequate for all demands made upon it. The low cost of drilling wells in the Gulf embayment has made it le for even the poorest to have plenty of good water. Railroads, cotton mills, ills, canning factories, and various public works have found the deep-well water er and better than surficial water. Along the southern coast in the rice area water igation is in many places obtained from artesian wells.

FIELD WORK.

field work for this report was done by Messrs. L. C. Johnson and A. F. Crider. Mr. on has been engaged for a number of years in geologic work in Mississippi and Ala- for the Alabama Geological Survey, and later for the United States Geological Survey. ollection of well records in this report was to a great extent made by him. In the 1904 Mr. Crider, under the supervision of Messrs. E. C. Eckel and M. L. Fuller, in of geology and water resources, respectively, collected further data on the geology :s relation to the underground waters of the State. The present report was pre- by Mr. Crider from the data obtained from these sources. Much valuable informa- ras also *obtained from* owners of wells, drillers, and others interested in the work.

GEOGRAPHY.

Mississippi occupies the central position of the States bordering on the Gulf of Me with Alabama and Florida to the east and Louisiana and Texas to the west. It l total area of 46,810 square miles, with an extreme length from north to south of 330 and a maximum width of 188 miles. It has 85 miles of coast line on the Mississippi S and a water frontage of 500 miles on Mississippi River.

The southern third of the State is largely covered with a fine growth of long-leaf y pine, which is being rapidly removed for lumber. There is still much valuable hard and short-leaf pine in the northern portion of the State. Besides the large areas of timber, much land in the State that was in cultivation before the civil war has since abandoned and now bears second-growth timber of a poorer quality, consisting p pally of short-leaf pine.

TOPOGRAPHY.

With the exception of a very small area in the northeast corner, the entire St Mississippi lies in the Coastal Plain. There is a gentle slope southward and wes from the region of northern Mississippi, where the highest hills rise about 700 feet sea level.

The larger streams, such as the Tombigbee on the east and the Mississippi on the have cut out large valleys and have worn them down almost to base-level. The sı streams have been constantly cutting back from the larger until there are but few undı interstream areas. The configuration of the State, therefore, has been greatly chı so that it can be separated into distinct topographic subdivisions.

The prevailing unconsolidated material of the various geologic formations has af the topography of the State but little. The rivers and smaller streams in many flow at right angles to the strike, thus cutting across the changing strata of the v formations.

Tennessee River hills.—The foothills of the Appalachian Plateau reach their western terminus in the northeast corner of Mississippi, near Tennessee River. streams flowing into the Tennessee are short and have a steep gradient. They hav cut deep channels into the older Carboniferous rocks, which stand out as high clif form the most picturesque scenery of the State.

The western side of the Tennessee River hills slopes more gently to the Tom Valley. The elevation of the ridge between the Tennessee and the Tombigbee feet or more. The elevation of the river at Columbus is 146 feet above sea level. gives a total descent of over 450 feet for the waters of the western slope of the Ten River hills.

Tombigbee Valley or Northeast Prairie.—The Tennessee River hills and the high extending north and south from the town of Pontotoc were once continuous acr broad valley of the Tombigbee. There is still a line of highland connecting the l the northeast with the plateau of the central part of the State, as the following elev will show: Iuka is 460 feet above sea level and to the south the hills rise still l forming the divide between Tombigbee River and the waters of the Tennessee and H The towns of Booneville and Ripley are situated near the crest of the divide; t mer is 532 feet, the latter 525 feet, above sea level. The broad valley of the Tom commonly known as the "black prairie," has an elevation ranging from 179 feet at to 532 feet at Booneville. The Tombigbee Valley is, therefore, a broad spoon- trough with a high rim on three sides.

North-central plateau.—The large area occupying the north-central part of the S a plateau sloping gently westward and southward from the divide between the Tom basin on the east and the Mississippi and Pearl River basins on the west. The has been greatly dissected by streams which still have deep, narrow valleys.

The plateau ends very abruptly along its western border, which is distinctly marked by a line of hills or bluffs extending from Memphis, Tenn., to Vicksburg, Miss., along the eastern rim of the Yazoo Delta. The bluffs stand 200 feet or more above the low-lying delta to the west. The difference in elevation of the Yazoo Delta and the central plateau to the east has caused the streams in central Mississippi to cut the bottoms of their channels more rapidly than they have widened their valleys.

The divide between the waters of the Tombigbee and Hatchee basins, which extends westward from the southern part of Tishomingo County to Ripley, continues unbroken with a gentle westward slope through central Tippah, northern Marshall, and De Soto counties almost to Mississippi River. The highest known elevation along this divide is near the town of Holly Springs, where the Illinois Central Railroad reaches 625 feet above sea level. The elevation of Olive Branch, in eastern De Soto County, is 421 feet, and near Horn Lake, which is but 12 miles from the Mississippi, the elevation is 340 feet.

Extending north and south, or at right angles to the east-west divide, is the Pontotoc divide, which separates the waters of the Tombigbee basin from those of the Mississippi, Pearl, Leaf, and Chickasawhay rivers. The Mobile, Jackson and Kansas City Railroad follows the ridge from Pontotoc to Louisville. Here the ridge turns southeast and passes into Alabama at the southern border of Lauderdale County. This divide has a general elevation throughout the State of about 500 feet.

Yazoo Delta.—The vast alluvial bottom known as the Yazoo Delta contains over 6,000 square miles lying between Mississippi River and the line of hills extending from Memphis through Batesville and Yazoo to Vicksburg. South of Vicksburg the Mississippi has a sharp wall on the east bank and a broad valley on the Louisiana side.

There is but little relief over the entire delta area. The larger streams, such as the Yazoo, Coldwater, Tallahatchie, Sunflower, and the Mississippi on the western boundary, have built up their banks by continual deposition so that the highest elevations are near the rivers, and there are gentle slopes to the interstream areas. When the Mississippi overflows the delta the banks of the larger streams are the last to be submerged.

There is a gradual slope southward from the Tennessee boundary, at an elevation of 217 feet, to Vicksburg, which is 94 feet above sea level. An east-west line from Greenwood to Greenville shows very little variation in the three known elevations. That at Greenwood is 143 feet, while the towns of Leland and Greenville are each 125 feet above sea level. This shows a very slight westward slope.

Jackson prairies.—Between the roughly carved region of the north-central plateau and the long-leaf-pine hills to the south is a belt of country known as the Jackson or central prairies. Its extent coincides with the area underlain by the Jackson formation, which is described on page 10.

The surface is more rolling than that of the regions to the north and south. Between Pearl River southeast of Canton and the town of Vosburg are large areas of level prairies covering hundreds of square miles. The streams on the north side of this belt as far east as Newton flow north and northwest to the Pearl; the streams on the south side flow to Strong, Leaf, and Chickasawhay rivers.

The elevation along the crest of the divide ranges from 426 feet at Vosburg to 475 feet at Forest. There is a gentle southward slope of less than 2 feet per mile from Louisville, which is 552 feet above sea level, to the Jackson prairies. The western third of the Jackson prairies is much lower than the region to the east. This is due to the valleys of Pearl and Big Black rivers. These rivers opposite Canton approach within 16 miles of each other, but the Big Black flows at a much lower elevation.

Long-leaf-pine hills.—The region from the Jackson prairies to the Gulf presents a diversity of topographic features. In many particulars it is analogous to the north-central plateau. The highest elevations rise more than 500 feet above sea level. The largest streams flow in very narrow valleys and are but little above sea level. The smaller streams are short and have steep gradients.

The interstream areas west of Pearl River have a maximum height of perhaps 600 feet. The Illinois Central Railroad from Beechgrove to Magnolia has many points above 425 feet in elevation, and reaches a maximum of 487 feet 5 miles north of Hazlehurst. This high plateau extends westward to within 10 to 15 miles of Mississippi River.

The region east of Pearl River is much lower except a small area south of Brandon, in southern Rankin and Simpson counties. Chickasawhay, Leaf, and Pascagoula rivers are but little above sea level, while the areas between have a maximum elevation of only 350 feet.

GENERAL GEOLOGY.

STRATIGRAPHY.

Though the geologic structure of Mississippi is very simple, the details of the stratigraphy are hard to make out. This is due largely to the extent to which the underlying rocks are covered by the more recent deposits, such as the alluvium and the "orange sand" or Lafayette formation.

The older rocks of the State represented by the Devonian and Carboniferous form the old sea floor, on which at a much later period the more unconsolidated beds belonging to the Cretaceous were laid down. The older rocks underlie the entire State, but come to the surface only in the northeast corner along Tennessee River.

The newer rocks outcrop south and west of this older mass in successive, roughly parallel bands. All dip slightly to the southwest, so that if an observer should start in Tishomingo County and travel through the State either south or west he would find himself continually passing over newer and newer series of rocks, until he finally reached the very recent alluvial deposits which fringe the Gulf and Mississippi River. The newer rocks, overlapping the older in the northeast, cover them to a greater and greater depth to the west and south. At the town of Corinth the hard rocks were struck at a depth of 450 feet from the surface, but, so far as known, no wells west or south of this have entered hard Paleozoic rocks.

The Cretaceous and Tertiary sediments were deposited in a vast trough comprising the present States of Mississippi, western Tennessee and Kentucky, and southern Illinois on the east side; and southeastern Missouri, eastern Arkansas, Louisiana, and southeastern Texas on the west. To the east, north, and west of the embayment was higher land which was worn down by erosion and from which material was carried by the streams and deposited in the trough-like embayment. Thus we have a series of strata dipping to the south and west on the east side of the embayment and to the east and south on the west side. The fine artesian-water basin in this region is due to the sandy, unconsolidated character of the sediments and the gentle slope of the sea floor on which they were deposited.

JULIUS BIEN & CO LITH N.Y.

The following section shows the geologic groups which are exposed in Mississippi and the relation of one group to another, the newest formations being at the top of the table and the oldest at the bottom:

General geologic section of Mississippi.

System.	Series.	Formation.	Water supply.
Quaternary		Recent alluvium. Sands, silts, and loam.	Large supply of unwholesome water.
		Yellow loam. Surface loam or brick clays of northwestern Mississippi.	Little or no water.
		Fossiliferous loess. Gray to buff-colored calcareous silt, containing land shells.	
		Port Hudson. Greenish to bluish clays, with interbedded sands. Calcareous concretions in lowest members.	Plenty of soft but unwholesome water.
		Lafayette. Red to yellow sands and iron-stained pebbles. Sands in places containing large amount of clay.	Good, wholesome, soft water. Source of shallow wells and springs in north-central and southern Mississippi.
Tertiary	Miocene?	Grand Gulf. Gray aluminous sandstones, interbedded with white to gray plastic clays in northwest; darker-colored clays containing lignitized wood and vegetable matter in southeast.	Source of flowing and nonflowing wells and numerous mineral springs.
	Miocene	Pascagoula. Calcareous sands, containing numerous fossils.	Probable source of flowing wells along the Gulf coast.
	Oligocene	Vicksburg. White, yellow, and blue crystalline limestone, interbedded with thin layers of indurated calcareous clay.	Little or no water.
	Eocene	Jackson. Gray calcareous clays, lignitic clays with gray siliceous sands, and some greensand.	Small amount of highly mineralized water.
		Claiborne group. Lisbon formation. Calcareous clays and greensands.	Little or no water.
		Claiborne group. Tallahatta buhrstone. Aluminous and quartzitic sandstones, greensands, and clay stones.	Plenty of water, which is sometimes highly mineralized. Source of deep flowing and nonflowing wells in the central and southern parts of the Yazoo Delta; also in Clarke County.
		Wilcox. Highly stratified sands and clays of various colors, with some beds of greensand marl.	Large supplies of soft water. Source of deep-well waters in the northern area of the Yazoo Delta. Water frequently mineralized.
		Midway group. Porters Creek. Gray aluminous clays.	Little or no water.
		Midway group. Clayton. Limestone, sands, and clays.	
Cretaceous		Ripley. Limestones, sandstones, and clays.	Plenty of wholesome water. Source of flowing wells in Pontotoc and Union counties.
		Selma chalk. White chalky limestone and blue calcareous clays.	Occasional springs of hard water.
		Eutaw. Siliceous sands and clays, with some greensand.	Water plentiful. Source of flowing and nonflowing wells over Selma chalk area. Water frequently impregnated with iron.
		Tuscaloosa. Variegated sands and clays.	
Carboniferous		Sandstone, limestone, and clays.	Numerous fresh-water springs; wells uncertain.
		Limestone and chert.	
		Siliceous chert.	
Devonian		Dark limestone and shale.	Little or no water.

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ary		Port Hudson. Greenish to bluish clays, with interbedded sands. Calcareous concretions in lowest members.	Plenty of soft but unwholesome water.
		Lafayette. Red to yellow sands and iron-stained pebbles. Sands in places containing large amount of clay.	Good, wholesome, soft water. Source of shallow wells and springs in north-central and southern Mississippi.
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		Midway group. Clayton. Limestone, sands, and clays.	Little or no water.
		Ripley. Limestones, sandstones, and clays.	Plenty of wholesome water. Source of flowing wells in Pontotoc and Union counties.
us		Selma chalk. White chalky limestone and blue calcareous clays.	Occasional springs of hard water.
		Eutaw. Siliceous sands and clays, with some greensand.	Water plentiful. Source of flowing and nonflowing wells over Selma chalk area. Water frequently impregnated with iron.
		Tuscaloosa. Variegated sands and clays.	Water plentiful. Source of flowing and nonflowing wells over Selma chalk area. Water frequently impregnated with iron.
erous		Sandstone, limestone, and clays. Limestone and chert. Siliceous chert.	Numerous fresh-water springs; wells uncertain.
n		Dark limestone and shale	Little or no water.

A. OUTCROP OF SELMA CHALK, THE CAP ROCK OF THE WATER-BEARING EUTAW SANDS.

B. TALLAHATTA BUHRSTONE CAP ROCK, OVERLYING LOOSE SILICEOUS SAND.

The surface of the outcropping Selma is a level or rolling prairie well adapted to agriculture. It embraces the larger part of Noxubee, western Lowndes, eastern Oktibbeha, the larger part of Clay, western Monroe, the eastern half of Chickasaw, almost all of Lee, western Prentiss, and central Alcorn counties. The west line of outcrop can be traced approximately through the towns of Scooba and Flatwood, and 3 miles west of Starkville to Houston. From here the line bends more to the east, through Troy, Blue Springs, Graham, and Antioch, and 2 miles west of Kossuth to the Tennessee line.

RIPLEY FORMATION.

Above the Selma chalk is the uppermost division of the Cretaceous, which has been called the Ripley formation, and which is made up of three substances. Dark-blue marl, containing abundant well-preserved fossils, occupies the upper part, and thinly bedded marly clays, alternating with sandy limestone, the lower part. The limestones are sufficiently porous to hold water. They come to the surface along the eastern border of the Ripley outcrop, and, with a westward dip of the strata greater than the slope of the surface, a small artesian basin is formed along the headwaters of Tallahatchie River.

The thickness of the formation, estimated by the width of the outcrop with a westward dip of 15 feet to the mile, is at a maximum, 280 feet.

The change from the rolling prairie surface of the Selma to the steep hills of the Ripley is very noticeable. The Ripley formation occupies a much smaller area than the Selma chalk, being widest at the north and wedging out entirely in Chickasaw County, at the town of Houston. From here south to the Alabama border the high hills of the Ripley as found in Tippah, Union, and Pontotoc counties are entirely wanting, except in a small area near the Alabama border. It is well exposed in Alabama, but wedges out in Kemper County, Miss., near the town of Shuqualak. From here to Houston the level "Flatwoods" of the Midway border on the prairie lands of the Selma chalk.

TERTIARY.

MIDWAY GROUP.

Clayton limestone.—The lowest division of the Tertiary is represented in Mississippi by a series of hard crystalline limestones, known as the Clayton limestone, and calcareous sandy marls. The limestone of this formation was referred by Hilgard to the Ripley, but later investigation by Harris and others has, on paleontologic evidence, placed it in the Midway.

The limestone has a maximum thickness of 20 feet near the town of Ripley. It is overlain by 20 to 30 feet of reddish to yellow sandy marl containing lime carbonate, and is slightly fossiliferous. The reddish color is due to a large amount of iron oxide. The color of these sands is very similar to that of the Lafayette, which is described on page 12.

The Clayton outcrop forms a narrow strip of territory from 2 to 6 miles wide, lying just west of the Ripley area. The line of the Mobile, Jackson and Kansas City Railroad follows the outcrop approximately from Middleton, Tenn., to Houston, Miss. From here the outcrop turns in a southeasterly direction west of Starkville and Macon and passes into Alabama southeast of Scooba.

No doubt the sands of the upper division are water bearing, but so far no wells to the west have penetrated the Clayton.

Porters Creek clay.—In Tennessee the name Porters Creek has been given to the clays immediately overlying the Clayton limestone. The calcareous sandy marl of the upper Clayton is overlain by 75 to 100 feet of gray nonfossiliferous clay, which forms the well-known "Flatwoods" area, extending from Tennessee into Alabama. This formation produces very stiff clay soils which are little used in the State for agricultural purposes. Roads through the "Flatwoods" often become impassable during the rainy season.

The Porters Creek outcrop occupies a narrow strip of country extending from Middleton, Tenn., into the State of Alabama, and has a width of 2 to 12 miles. In the north it is hemmed in between the Ripley hills on the east and the Wilcox plateau on the west. South

of Maben the range of hills on the east border of the Wilcox formation rises 100 feet or more above the Porters Creek, and is more distinct than the line between the Porters Creek and the Clayton limestone. The western border is easily traceable from 4 miles east of Maben due south through Oktibbeha County; here the line turns in a more southeasterly direction, running through Shuqualak and Scooba into Alabama.

The Porters Creek clay marks an important horizon between the waters of the Ripley and Wilcox horizons. The rainfall entering the outcropping sands of the Ripley follows these beds, which dip gently to the west. The overlying Porters Creek clay prevents the water from rising, and it is thus confined and given pressure as the reservoir becomes full.

WILCOX FORMATION.

The important division of the Tertiary known as the Wilcox formation occupies a large area of northern Mississippi. It was originally named the Lignitic by Hilgard, and Safford, State geologist of Tennessee, termed it the La Grange group.

The term "Lignitic" as used by Hilgard has been objectionable because it is not a locality name. As used by Safford the term "La Grange" included the present Lafayette and portions of the Cretaceous, so it has likewise been discarded. The present name, Wilcox, was first given in some unpublished work by Eugene A. Smith, State geologist of Alabama, for the reason that typical strata of the former Lignitic of Hilgard are exposed at Wilcox, Ala. The name has been adopted by the United States Geological Survey as the formation name to include the complex mass of sands, clays, lignites, marls, etc., between the Porters Creek clays below and the Tallahatta buhrstone above.

Owing to its more or less sandy character throughout, the Wilcox forms the most important water horizon of northern Mississippi. The coarse-grained, unconsolidated sand beds are often interbedded with seams of lignite and white and chocolate-colored clays. The clays of the upper division, as at Grenada, are very dark and may properly be called shale. In the eastern half of the area loosely bedded sands predominate. The western portion, which is a series of irregularly cross-bedded sands and sandy clays, is separated from the eastern by a more or less regular line of white and chocolate-colored clays, which are used for making stoneware.

The thickness of the group is estimated from the width of the outcrop to be 750 to 800 feet. The deep well at Memphis is reported to have passed through the Wilcox at a depth of 963 feet.

In Alabama, Smith has divided the "Lignitic," the equivalent of the Wilcox, into six members. Each contains one or more marl beds from which distinguishing fossils are obtained. He includes in the "Lignitic" the Porters Creek clays, which in Mississippi are mapped with the Midway.

The Wilcox covers the largest territory of any formation in northern Mississippi. It occupies the entire area lying between the Porters Creek outcrop and the bluffs on the eastern rim of the Yazoo Delta as far south as Grenada The west edge south of Grenada is a line extending southeast 6 miles east of Winona, west of Philadelphia, and southwest of Meridian.

The entire Wilcox group is very important as a water-bearing formation. The numerous beds of sand interbedded with clays form various water horizons throughout the formation. The shallow artesian wells at Batesville and Coffeeville, begun below the yellow loam and Lafayette, show that there are beds of clay in the upper division of the Wilcox sufficiently persistent and compact to confine the water below the clay and to form artesian basins in the upper Wilcox.

CLAIBORNE GROUP.

The Claiborne is divisible on lithologic grounds into two distinct formations. The lower of these is the Tallahatta buhrstone, or "siliceous Claiborne;" the upper includes the Lisbon beds, or "calcareous Claiborne."

Tallahatta buhrstone.—This formation, called "siliceous Claiborne" by Hilgard, consists chiefly of glauconitic coarse-grained micaceous sandstone, siliceous and aluminous clay

stones, and a white siliceous sandstone that is almost quartzite. The estimated thickness is 350 feet.

The formation outcrops in a belt of territory between the Wilcox and Lisbon beds, and varies in width from 10 miles in northeastern Clarke County to 30 miles in Leake and Winston counties. The eastern line of outcrop is traceable from the Alabama line 4 miles south of Hurricane Creek post-office to Eastville; thence it swings southwest nearly to Sterling, south of Meridian; thence it bends northwest past Battlefield, Philadelphia, Plattsburg, Hinze, and French Camp, 6 miles east of Winona, and west of Grenada. No trace of the Tallahatta has been found north of Yalobusha River.

For the eastern part of the delta and the central portion of the State lying south of the Tallahatta outcrop, this formation forms a very important water horizon. The extensive area underlain by the formation and the porous texture of its materials make it well suited for absorbing a large amount of rainfall. The water-tight clays at the base of the overlying formation confine the water in the Tallahatta buhrstone.

Pl. II, *B*, shows a hard cap rock of sandstone at the top of the section, with loose siliceous sand immediately underlying it. Over extensive areas in the Yazoo bottom flowing wells are obtained when the drill passes through the hard layer of sandstone and enters the sands below. The ledge of sandstone, which varies in thickness from 12 to 30 inches, is very hard, in places almost a quartzite, and often requires several days' drilling to pass through it.

Lisbon formation.—Above the Tallahatta is a series of beds which Hilgard called "calcareous Claiborne" and which will be termed the Lisbon formation. The series is about 150 feet thick, and is composed of calcareous sands and laminated and lignitic clays. The character of the surface is little affected by the Lisbon, which is almost everywhere overlain by the Lafayette.

In Alabama the area underlain by this formation is very limited in extent, but in Mississippi it widens out and occupies the territory from southeastern Clarke to southern Carroll County, varying from 5 to 25 miles in width.

The thick mantle of Lafayette covering the Lisbon area furnishes plenty of good water, and the water-bearing horizons of the Lisbon have therefore not been developed.

JACKSON FORMATION.

In Alabama the Jackson and the succeeding formation, the Vicksburg, have been classed together under the name of St. Stevens. In Mississippi, however, they can usually be separated very readily and will be treated as two distinct formations.

The essential materials of the Jackson group are gray calcareous and lignitic clays and sands. The outcrop occupies a belt of country 10 to 30 miles wide, extending southeast and northwest across the State from Yazoo to the Alabama line north of Waynesboro. The area is known as the "central prairie."

There are no continuous water horizons in the lower or middle Jackson. It is usually barren of water, and when found the water is very impotable. Wells in this region obtain their water either from the base of the Lafayette or from the upper member of the Tallahatta buhrstone. Flowing wells are obtained along the lower streams.

The Jackson has usually been described as "marls" and clays, but recent investigations along the line of contact with the Vicksburg have shown that there are between 50 and 75 feet of yellow, gray, or white siliceous sand at the top of the Jackson. Whether from a paleontologic standpoint this should be considered Jackson or Vicksburg we are unable to say, since no fossils have been found in the sands. They are regularly stratified, showing that they were deposited in a quiet sea with little or no current. In places near the surface the sands are slightly cemented with iron oxide, causing some layers to resist erosion more than others.

Pl. III, *A*, represents the highly stratified character of the siliceous white to gray sands of the uppermost member of the Jackson formation. These sands, which are very porous, are exposed through erosion over large areas in Mississippi and absorb large amounts of water, the water table in such cases very nearly reaching the surface (Pl. III, *B*).

SON SANDS SHOWING CHARACTER OF MATERIAL AND EROSION AND CATCHMENT CONDITIONS.

UPPER PART [illegible] FORMATION SHOWING WHITE OR GRAY [illegible] SAND PHASE

is is the only horizon of the Jackson which may become of any importance as a water-
er. South of its outcrop there are no deep wells which are known to derive their
rs from this horizon, so that its importance in this respect is not known.

VICKSBURG LIMESTONE.

is formation, first studied by Conrad at Vicksburg, occupies a very limited area south
e Jackson. It consists of crystalline limestone in beds varying from 1 inch to 3 feet
ickness, alternating with sandy calcareous strata of marl of about the same thickness.
e is a marked difference in the appearance of the different beds of limestone. Those
the surface are soft and yellow, while the more compact beds unaffected by surface
hering are blue. The rapidity with which the limestone breaks down under the action
athering agents makes it unsuited for building stone or road material. The Vicksburg
no importance as a water-bearing formation.

PASCAGOULA FORMATION.

A. Smith has distinguished along Pascagoula River in Mississippi a series of calcareous
s bearing a Miocene fauna overlying the Vicksburg limestone and underlying the
mass of lignitic sands and clays of the Grand Gulf. He has given it the name Pasca-
formation. No other outcrops have as yet been found in the State, but deep-well
gs along the Gulf coast have brought up calcareous sands containing fossils which
Johnson refers to the Pascagoula. It was at first thought that the Pascagoula was
ger than the Grand Gulf, or doubtless a fossiliferous horizon in it, but more recent
tigation has shown that the Pascagoula clearly underlies the Grand Gulf.
the type locality of the Pascagoula formation, as well as at Mobile and points along
ulf in Mississippi, the Pascagoula beds are overlain by Grand Gulf beds; but further
work will be required before the relation of the two series (Grand Gulf and Pascagoula)
her areas can be stated with certainty. Such later work may require a redefinition
e term Grand Gulf. Owing to the limited area of outcrop the formation is not shown
e map. The Pascagoula furnishes an important source of fine artesian water along
oast.

GRAND GULF FORMATION.

e Grand Gulf formation is used in the sense in which it was originally defined by
rd. It is, therefore, not a homogeneous series of beds, but may include formations
ferent age. It is certain, however, that everything here included in the Grand Gulf
wer than the Vicksburg limestone and older than the Lafayette or "orange sand"
ation.
e Grand Gulf is made up almost entirely of sandstones and clays. The sandstones
sually but slightly cemented and are made up of sharp grains of silica, with more or
lumina and iron pyrites. The color varies from a pure white to a rusty yellow, the
resulting from the oxidation of the sulphide of iron. These sandstones are especially
on in the northwestern part of the area underlain by the Grand Gulf—that is, northwest
ine drawn from Fort Adams to Raleigh. Southeast of this line sandstones are very
Elsewhere the formation consists of bluish to black clays, shales, and unconsolidated
. The thickness of the Grand Gulf, as ascertained from deep-well borings, is 750 to
et.
Grand Gulf underlies most of that part of Mississippi south of a line drawn as follows:
ing at the river a few miles south of Vicksburg it runs parallel to and a mile or so
of the Alabama and Vicksburg Railroad, and passes a short distance north of Ray-
l. Here the boundary line bends rather abruptly southeast, crossing the Illinois
al Railroad between Terry and Byram. It then turns northeast passing through
erey to Brandon, at which point it finally assumes a southeasterly direction through
el, Raleigh, Vosberg, and Waynesboro into Alabama. All the State south of this line is
ied by the Grand Gulf group (except the narrow belt of Port Hudson clays which

border the Gulf coast in Hancock, Harrison, and Jackson counties and are described on page 13.)

The area along the Mississippi from Fort Adams nearly to Vicksburg, and in Lincoln, Copiah, Hinds, Simpson, and Rankin counties, contains the only outcrops of the sandstones. In these localities it alternates with the bluish-tinted clays. At Raymond and Star the sandstones attain a thickness of 15 feet and appear near the summit of the hills, with thinner strata below alternating with semiplastic clays.

The sandstones are wanting south and east of the line mentioned above, and the formation is essentially indurated, laminated sands and clays of various characters, from the white plastic clays to those containing lignitized tree trunks. Beds of lignite are also of frequent occurrence.

Many of the fine artesian wells along the Gulf derive their waters from the Grand Gulf formation. In the region of Hattiesburg and Columbia flowing wells are obtained from its lower division.

LAFAYETTE FORMATION.

Resting unconformably upon all the underlying formations from the Grand Gulf to the Carboniferous is a thin veneering of the Lafayette formation. This is a fresh-water deposit, composed chiefly of dark-red to light-red, coarse, round-grained sand, which in places contains more or less clay and water-worn pebbles. It varies from a knife-edge to 50 feet or more in thickness. The latter thickness is very rare, and it is more often found to be less than 10 feet.

In Tishomingo and Itawamba counties the Lafayette contains large deposits of water-worn pebbles, gravel, flint, chert, and some quartz, extending in a north and south belt 5 to 10 miles wide. Another belt of similar material occurs along the eastern edge of the loess formation, in the counties of De Soto, Tate, Panola, and Yalobusha. The shape of the pebbles is somewhat different in this belt—those of the above-mentioned counties being worn into an oblong egg shape, while here they have a more rounded form; they also contain more quartz. Still another belt, which is practically a prolongation of the western belt, is found in the southern part of the State. The main line of the Illinois Central Railroad runs along the outcrop of the gravel beds from Jackson to the Louisiana border.

The Lafayette was deposited upon a deeply eroded surface of the older formations, which accounts in part for the irregularity in its thickness. Since the deposition of the Lafayette there has been a large amount of erosion, and in many places the whole formation has been removed. In the areas of the Selma chalk and the Porters Creek formation the Lafayette is practically absent. East of the Selma chalk area there is more or less of the Lafayette covering the Eutaw, Tuscaloosa, and Carboniferous. In northern Mississippi, particularly in Marshall and Lafayette counties, where the formation was first described and named, the Lafayette, when present at all, is only a few feet thick, but in many places it is wanting. It thickens to the south, reaching its maximum in southern Mississippi, where it is said to be 200 feet thick. No such thickness, however, was observed in the course of the present work.

In various localities in the State the iron in the Lafayette has cemented the Indian red sands and formed a ferruginous sandstone, which is often mistaken for pure limonite or brown hematite. These deposits are uniformly of very shallow depth, but may extend over considerable areas. The ferruginous sandstone is always formed immediately above a bed of clay or some material which checks the downward flow of water. The water passing through the Lafayette becomes saturated with iron oxide, and, on being checked at the base by the underlying clay, deposits the iron, which cements the sands into a compact mass. This mass is constantly increased by the addition of more iron from the iron-charged waters. Gradually the overlying material is worn away until the ferruginous sandstone is reached, which resists the action of erosion and often forms a scarp along the tops and sides of hills.

Where the Lafayette is thick enough it forms the source of a very desirable and easily accessible supply of potable water. The great amount of sand in the formation forms a natural filter. Many of the springs of the State issue from the base of the Lafayette, where it rests on a bed of water-tight clay, a lignite seam, or limestone.

QUATERNARY.

PORT HUDSON FORMATION.

The formation immediately above the Lafayette has been called the Port Hudson, from the typical exposure at Port Hudson, Miss. It is composed of clays, silts, and unconsolidated sands containing old cypress stumps representing different generations superimposed one upon another. The thickness of the formation, as determined from criteria obtained along the Gulf, is 100 to 125 feet.

The Port Hudson area occupies a narrow belt along the Mississippi south of Vicksburg, the low-lying belt of country between Yazoo and Mississippi rivers erroneously called the "delta," and a small area bordering on the Gulf of Mexico. There is a possibility that the so-called Port Hudson of the Yazoo Delta belongs to a much younger age than the Port Hudson farther south, but for the present it is all mapped as one formation. The vast body of land called the "delta" is but a few feet above the common high-water mark of Mississippi River, and was overflowed in times of very high water until as late as 1884. The investigations of Hilgard have shown that the formation was deposited in a fresh-water embayment during the slow depression of the continent at the close of Glacial time, and that it was not due to the successive overflows of the old Mississippi River.

As far east as Union County, along Tallahatchie River, old inhabitants say the bottom land has been elevated in their lifetime from 2 to 4 feet by successive overflows of the river, a fact easily proved by noting the difference in elevation of the surface on the outside and inside of hollow cypress stumps. The gradual elevation of the bed of the Mississippi in recent years and the vast alluvial deposits show that the Port Hudson formation may possibly be of river origin.

Water in large quantities may be obtained very near the surface over the entire area of the Yazoo Delta by simply driving down a pipe with a strainer attached at the lower end. The large amount of vegetable matter in the Port Hudson sediments causes a very unwholesome drinking water.

FOSSILIFEROUS LOESS.

East of the Mississippi, south of Vicksburg, for a width of 12 to 15 miles, and bordering the eastern limit of the Port Hudson north of this place, is the loess or "Bluff" formation. This is made up of a homogeneous, silty, calcareous loam containing a great number of land shells.

YELLOW LOAM.

Immediately overlying the loess and extending from 25 to 35 miles farther east than the typical loess is the formation which Hilgard has called the "yellow loam." This is an unstratified mass of sandy clay or loam, entirely void of fossils, and of a uniform pale-yellow to light-brown color. East of the calcareous-loess area it forms a thin covering over the Lafayette, when that is present, and has a maximum thickness in northwestern Mississippi of 25 feet. It is also present in the central and southern parts of the State, but is much thinner here than farther north.

RECENT ALLUVIUM.

The most recent strata of the State, occurring along the larger streams, particularly along the Mississippi, have been mapped with the Port Hudson formation.

UNDERGROUND-WATER RESOURCES.

SOURCE OF UNDERGROUND WATERS.

In a series of sands and clays, such as those of the Coastal Plain deposits of Mississi the deposition of which took place beneath the salt waters of the ocean, the groundwa are derived from two diverse sources. The salt waters encountered in certain of the de wells represent, in all probability, ocean waters which have been retained in the dep since the accumulation of the latter beneath the sea, while the fresh waters encountere all of the shallow and in a large proportion of the deep wells have been derived from rainfall.

RAINFALL.

Mississippi has an average rainfall, according to the Weather Bureau, of about 51 in the precipitation varying from 49 inches at the northern edge of the State to 54 inches

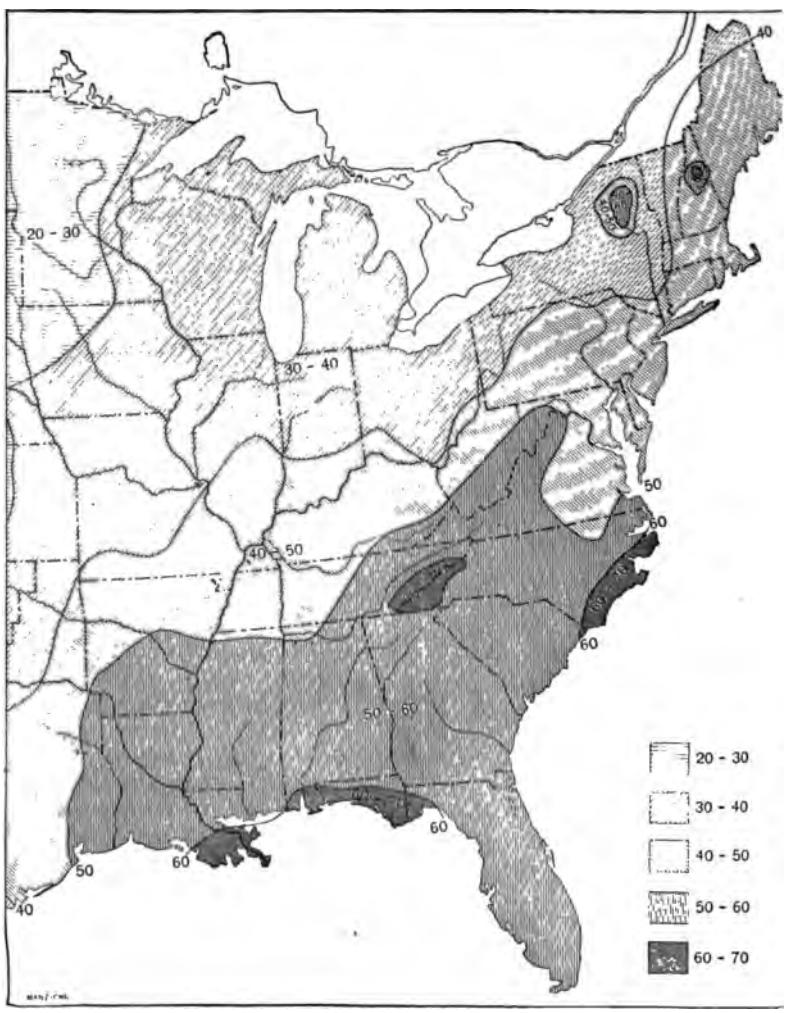


FIG. 1. Rainfall map of eastern United States.

the coast. The greatest annual precipitation recorded in the State was 101.47 incl *Bay St. Louis in 1900*, and the least, 22.49 inches, at Kosciusko in 1889. Octobe *November are usually* the dryest months of the year.

Not only does the rainfall vary in total amount from year to year, but the amount in a given district varies greatly. This fluctuation is so large that a rainfall map for a given year has little value. Unfortunately no map showing average precipitation in detail is available, but the general average rainfall for the State and its relation to adjacent areas is shown in fig. 1.

DISPOSAL OF RAINFALL.

The precipitation is taken up mainly in three ways—(1) by evaporation directly from the surface before the rain is absorbed, (2) by direct run-off of the water into the streams without its being first absorbed by the soil, and (3) by absorption into the ground.

A very large proportion, probably 40 to 50 per cent, of the water absorbed by the ground in Mississippi is returned again to the atmosphere by evaporation, either directly from the surface or through the vegetation with which the surface is covered. Of the remaining ground water it is estimated that 1 per cent or less is permanently taken up in chemical combination by the rocks. The rest joins the underground water body occupying the pores and crevices within the rocks and other materials. Where the conditions have been such that water could penetrate the rocks these have long since been filled to saturation up to drainage level, so that practically all the excess of ground water not removed by evaporation finds its way to the valleys and other low spots, where it forms springs or joins the streams by general seepage. The amount thus returned to the streams is a large proportion of the total run-off, the immediate run-off, or that portion of the flow which has never been absorbed by the soil, being estimated at from 5 per cent of the rainfall in the case of certain sandy districts to 33 per cent in an area where the rocks are of several diverse types. It is thought that in the entire State probably not more than 15 per cent is removed by the direct run-off.

Detailed observations of the relation of rainfall to run-off have been made in the Tombigbee and Yazoo River basins. In the former basin, north of Columbus, there was in 1903 a rainfall of 42.69 inches, while the run-off was 19.88 inches, of which 85 per cent, or 16.87 inches, is estimated to have passed through the soil before joining the streams. In a way this may be taken as representing the surplus ground water for the year of the computation. Reduced to gallons, this surplus amounts to about 458,000 gallons per acre. In the Yazoo basin the run-off was 17.41 out of 42.68 inches, the surplus computed in the same manner as above being 402,300 gallons per acre. When it is remembered that a well flowing 100 gallons a minute ranks as a large well, and that the surplus rainfall of every 130 acres would furnish such a well, the vast amount of available ground water, yielding approximately 5 wells to each square mile, or about 234,000 to the State, will be better understood.

DEPTH OF PENETRATION OF WATER.

Water penetrates downward through the pores of the rocks and through cracks, fissures, and other passages. Theoretically it can pass downward until the rock pressure becomes so great that there are no openings, a condition which is estimated to exist at a depth of about 6 miles. As a matter of fact, however, active circulation of ground water takes place mainly in stratified rocks, and then only within a relatively short distance of the surface, usually from 1,000 to 2,000 feet. It is commonly useless to expect unmineralized waters at greater depths.

CAPACITY OF MATERIALS TO HOLD WATER.

The amount of water which can be held by different materials varies greatly. That absorbed by some of the common rocks is shown in the following statement:[a]

Amount of water absorbed by some common rocks.

[In quarts per cubic foot.]

Granite	½-¾
Limestone (dense)	¾-1½
Dolomite (including porous limestones)	1-5
Chalk	4-8
Sandstone	2-6
Sand	8-10
Clay	10-12

Rocks have the greatest absorptive power when the grains are of uniform size. Where there is a mixture of fine and coarse grains much less water is taken up. Unfortunately the amount which a given material will yield does not depend entirely on the amount which it contains. For instance, clay, though it has a high porosity, holds water with great tenacity and will yield but little to a well.

RATE OF PERCOLATION.

In general it may be said that the coarser the sand and the smaller the amount of clay the more rapid the rate of movement, but this also depends largely on other factors, such as pressure and temperature. With a given material nearly twice as much water will percolate through a stated area at a pressure of 20 pounds per square inch as will pass through it at 10 pounds. Likewise the percolation is nearly twice as rapid with the water at 100° F. as it is at 50° F.

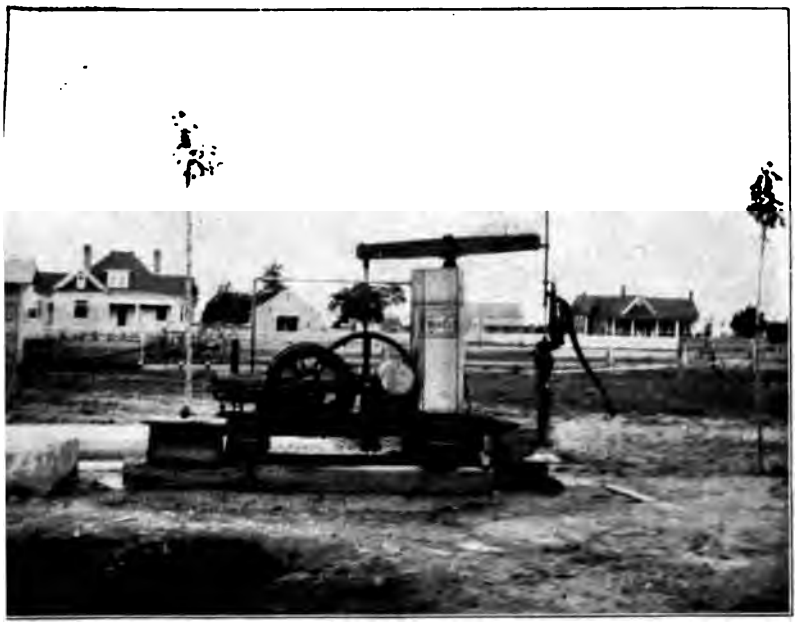
GROUND-WATER DIVISIONS.

The earth's crust may be divided into three zones, according to the conditions of underground-water circulation: (1) The unsaturated zone, extending from the surface of the ground down to the upper surface of the ground-water body, or the "water table," as it is commonly termed; (2) the zone of shallow or, as they are frequently termed, "surface waters," extending from the level of the water table down to the first impervious stratum of considerable extent; and (3) the zone of deep-seated waters, or those lying below the first impervious stratum. The unsaturated zone may contain a considerable amount of water, but it is not stationary, being simply in transit from the surface downward to the water table, or surface of the zone of shallow waters. The zone of shallow waters as here defined is a unit, but the zone of deep-seated waters is not a unit, as there are in most cases several subdivisions, depending on the presence of impervious strata within the zone.

GROUND-WATER TABLE.

The water table in general shows a somewhat close agreement with the slope of the surface of the land, tending to flatness under plains and to inequalities, similar to those of the surface, in the hilly regions. The undulations of the water table, however, are less marked than those of the land surface, the water standing considerably below the top of the ground at the crests of the hills while it is practically at stream level in the valleys. The depth of the ground water below the surface depends on the rate of lateral percolation into the streams as compared with the rainfall. In the eastern United States the permanent ground-water level is seldom at a great depth below the surface, water being commonly obtained within 30 to 40 feet of the top of the ground in lands of moderate elevation, while in valleys supplies are often obtained at depths of 15 feet or less. In the arid regions, on the other hand, the ground-water level may be many hundred feet below the surface.

[a] Data furnished by M. L. Fuller.

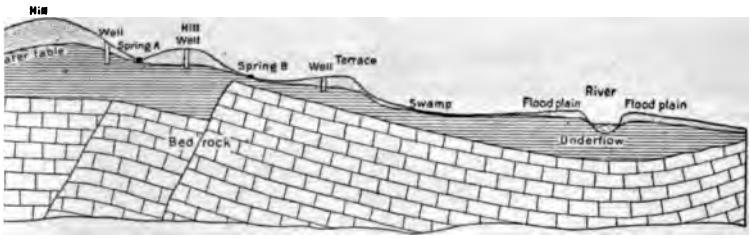


A. GASOLINE PUMP AND METHOD OF ATTACHMENT.

B. APPARATUS FOR PUMPING BY HORSEPOWER.

Photograph by M. L. Fuller.

tions of the ground-water table to the surface in a region of uneven topography in fig. 2.



al section through valley and hills, showing the position of the ground water and the ns of the water table with reference to the surface of the ground and to bed rock. (After

RECOVERY OF UNDERGROUND WATERS.

waters.—The waters of the shallow zone are recovered through springs or seepages n or driven wells. The manner in which the former emerge has already been sug- ne paragraph relating to the ground-water table, the water coming to the surface his table is cut by a valley or other depression. This natural process of recovery ented by open wells, which are simply circular excavations dug from the surface ly below the water table. To the use of this form of well there are many objec- of which are considered on pages 74 and 75. (Pl. VI, *B*, p. 74) A better form ne driven type, which is made by forcing a pipe with an open end, or with a per- nt, downward into the ground-water body, by which process the possibility of ion by the entrance of surface waters is prevented. (Pl. VI, *A*.) In both types e water must be raised by bucket, pump, or other mechanical means. Two pumping water which are in common use are shown in Pl. IV. The use of gas- s promises to be very successful in localities where windmills are not practicable.

ted waters.—The deep-seated waters generally occur in gently dipping porous en more impervious strata. In general the water escapes at the surface only is a break in the impervious covering, allowing it to come up along fissures or ces. Springs and wells depending on deep-seated waters are more independent show relatively slighter changes of temperature, are more free from contamina- re more stable in flow than those from the more shallow sources. The deep- ers are artificially brought to the surface by means of deep wells. In such wells generally under pressure and rises far above the point at which it is encountered, ses reaching to or even considerably above the level of the ground at the well, others it may fail to reach the surface, and pumping must be resorted to. In paper the term "artesian" is used to designate all wells in which the water is rial hydrostatic pressure and will rise in the well when the impervious capping ed.

ARTESIAN REQUISITES.

f artesian requisites are an inclined pervious bed lying between two impervious aving its outcrop at a height greater than the surface at the well, an outcrop absorption, a rainfall sufficient to furnish the necessary supply, and the absence leakage. Until recently these conditions have, in fact, been regarded by every ntial, but it has lately been shown that flows can be obtained even in uniform arrangement of the grains in horizontal laminæ, due to stratification, so opposes of the water that it can rise through the well with much greater ease than sand itself. In fact, it seems likely that a difference in the level of the water sely adjacent regions sufficient to furnish a working head is the only essential

requisite of an artesian flow.[a] Four of the most common types of artesian conditio illustrated in the accompanying diagrams (figs. 3, 4, 5, 6).

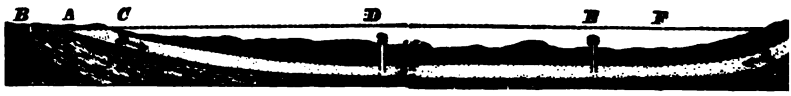


FIG. 3.—Section showing certain conditions governing artesian wells. A, a porous stratum impervious beds below and above A, acting as confining strata; F, height of water level in bed A, or, in other words, height of reservoir or fountain head: D, E, flowing wells sp from the porous water-filled bed A. (After Chamberlin.)

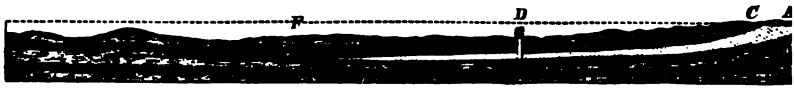


FIG. 4.—Section illustrating thinning out of porous water-bearing bed A, inclosed between vious beds B, C, thus furnishing conditions for artesian well D. (After Chamberlin)

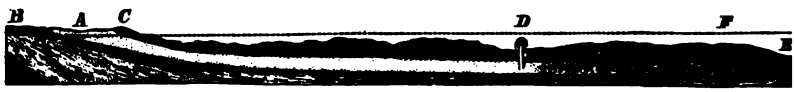


FIG. 5.—Section showing transition from porous to impervious bed. A, a close-textured, imp bed, inclosed between impervious beds B and C, furnishing conditions for an artesian well D. Chamberlin.)

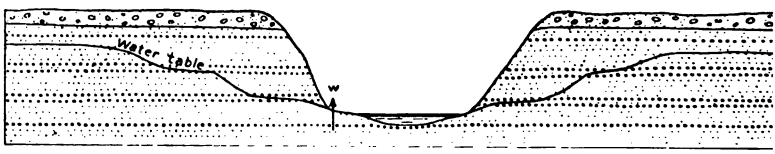


FIG. 6.—Section showing conditions favorable to flows from unconfined sandy strata. (After I

SPECIAL CONDITIONS IN COASTAL PLAIN FORMATIONS.

In early treatises on artesian conditions it was argued that flowing wells could be ob only in low regions with higher land on either side—that is, the artesian well mu located in a synclinal basin. But such is not the condition in the Atlantic and the sou portion of the Gulf Coastal plains.

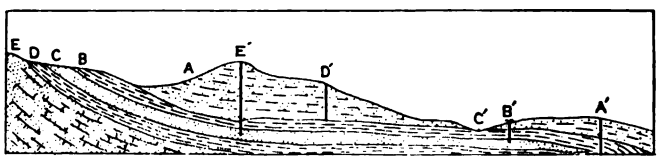


FIG. 7.—Section showing conditions governing artesian and flowing wells in the Costal Plain tions. A, surface sands—clays and sands; B, impervious stratum of clay; C, water-bearing D, impervious stratum of clay; E, Pre-Coastal Plain deposits of limestone and sandstone. A′, common wells; B′, flowing well; C′, spring

The great series of unconsolidated sediments belonging to the Gulf Coastal Plain deposited upon a sea floor of older rocks sloping gently seaward from their present ou along the foothills of the southern Appalachian plateau. The Coastal Plain sedi are thickest at the Gulf coast, where they reach a thickness of more than 2,000 feet. become thinner and thinner to the north, finally disappearing at the outcrop of the rocks.

[a] Fuller, M. L., Artesian flows from unconfined sandy strata: Engineering News, vol. 52, pp. 3

The sand and clay sediments of Mississippi were deposited in comparatively shallow water near the old shore. In these deposits the fine supply of artesian and deep-well waters are stored. It frequently happens in this State that the sediments which are water-bearing in one locality change in character in a very short distance and become impervious to water. We shall present only five conditions, which will serve to illustrate the character of the sediments and the possibilities of getting water in the State.

In fig. 7, E represents the older rocks on which the Coastal Plain deposits D, C, B, A were laid down. C is a water-bearing sand incased between two impervious strata, D and B, which prevent the water from leaking out and keep it under hydrostatic pressure. The stratum C cuts out before reaching A′, on the extreme right side of the figure; here there is a water-bearing sand at the surface, but it will not furnish artesian water because of the lack of an upper confining stratum. A′, B′, D′, and E′ are wells. There is no flow at A′ because the artesian bed C fails to reach it. B′ enters the artesian bed C and the water flows above the surface. C′ is a spring. The well at D′ is a strong stream of good water, but does not flow because of lack of depth. The well at E′ enters the artesian sand and the water rises to within a few feet of the surface, but does not flow because the elevation of the mouth of the well is above the head of the water.

UNDERGROUND-WATER HORIZONS OF MISSISSIPPI.

The Gulf embayment includes western Florida and Georgia, southern Alabama, all of Mississippi, western Tennessee and Kentucky, southern Illinois, southeastern Missouri, eastern Arkansas, Louisiana, and southeastern Texas. Within this vast basin there are

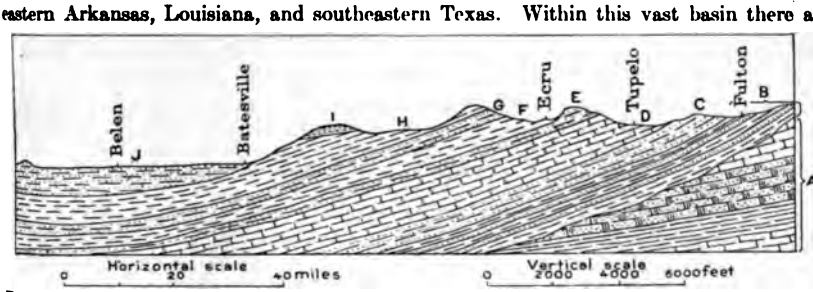


FIG. 8.—Cross section from Alabama to Mississippi River, in latitude of Tupelo. J, Port Hudson; I, loess; H, Wilcox; G, Porters Creek; F, Clayton; E, Ripley; D, Selma; C, Eutaw; B, Tuscaloosa; A, Paleozoic.

several distinct artesian-water horizons. With the exception of a small area of northwestern Alabama the gathering ground of the different water-bearing horizons of Mississippi lies entirely within the State.

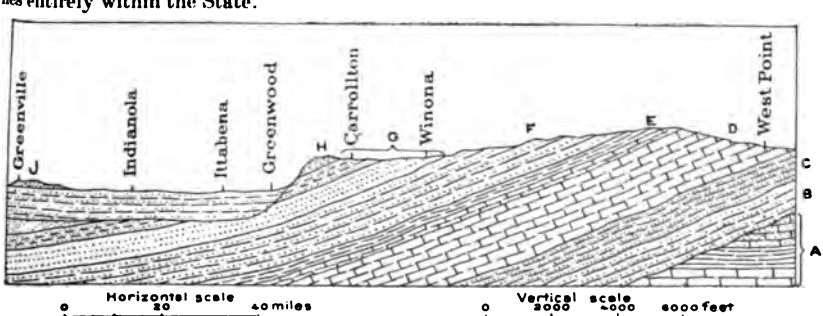


FIG. 9.—Cross section from West Point to Greenville. J, river alluvium; I, Port Hudson; H, loess; G, Tallahatta; F, Wilcox; E, Midway; D, Selma; C, Eutaw; B, Tuscaloosa; A, Paleozoic.

In the cross sections of the State (figs. 8, 9, 10, and 11) an effort has been made to show the relations of water-bearing to nonwater-bearing horizons. These have been prepared from a study of the well records and the surface outcrops of the different geologic formations.

There are seven distinct artesian-water horizons in Mississippi. Beginning with the lowest member of the Cretaceous we shall treat them as follows: (1) Tuscaloosa-Eutaw, (2) Ripley, (3) Wilcox, (4) Claiborne, (5) Pascagoula, (6) Grand Gulf, (7) Lafayette.

TUSCALOOSA-EUTAW HORIZON.

The upper division of the Tuscaloosa and all of the Eutaw formation constitute one artesian-water horizon. The lower division of the Tuscaloosa consists of heavy-bedded, compact clays of various colors. These clays form the lower confining beds of the Tuscaloosa-Eutaw horizon. The "blue rock" of the lower Selma forms the upper confining beds. Between these two water-tight beds are 1,000 to 1,200 feet of cross-bedded sands and gravel, interbedded with more or less irregular strata of sandy clays and occasional beds of lignite.

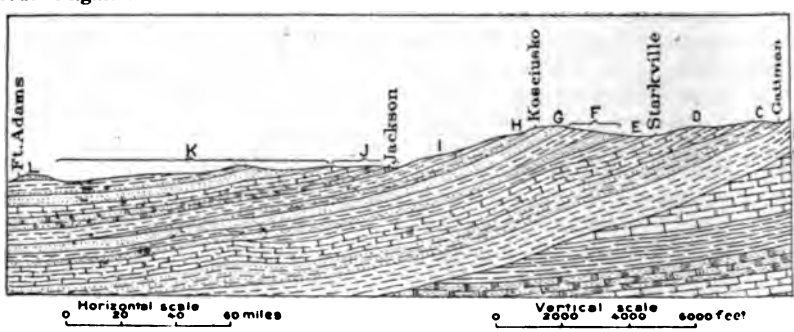


FIG. 10.—Section from Gattman to Fort Adams. L, loess; K, Grand Gulf (sandstone and clay); J, Vicksburg (limestone); I, Jackson (clays and marls); H, Claiborne; G, Tallahatta (sandstone); F, Wilcox (sands and clays); E, Midway (limestone and clays); D, Selma (limestone); C, Eutaw (sands and clays); B, Tuscaloosa (sands and clays); A, Paleozoic (limestone, etc.).

If the numerous beds of clay were continuous throughout the formations they would divide the group into separate water horizons, and no doubt some of the beds do extend over large areas and locally affect the height of the water horizons. Where these formations have been most carefully studied at the surface it has been impossible to trace any definite horizon of sand or clay for a great distance. Along some of the river bluffs, where good exposures are obtained, the material often changes within a hundred feet from a

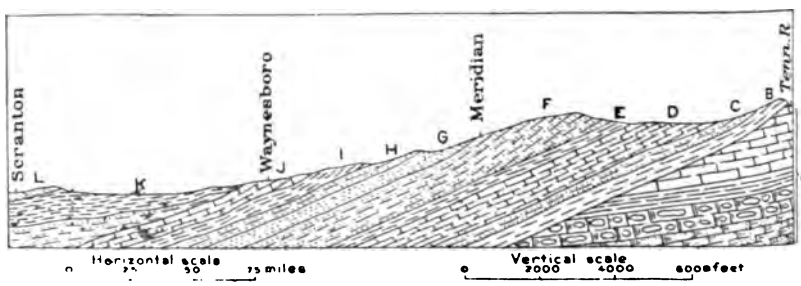
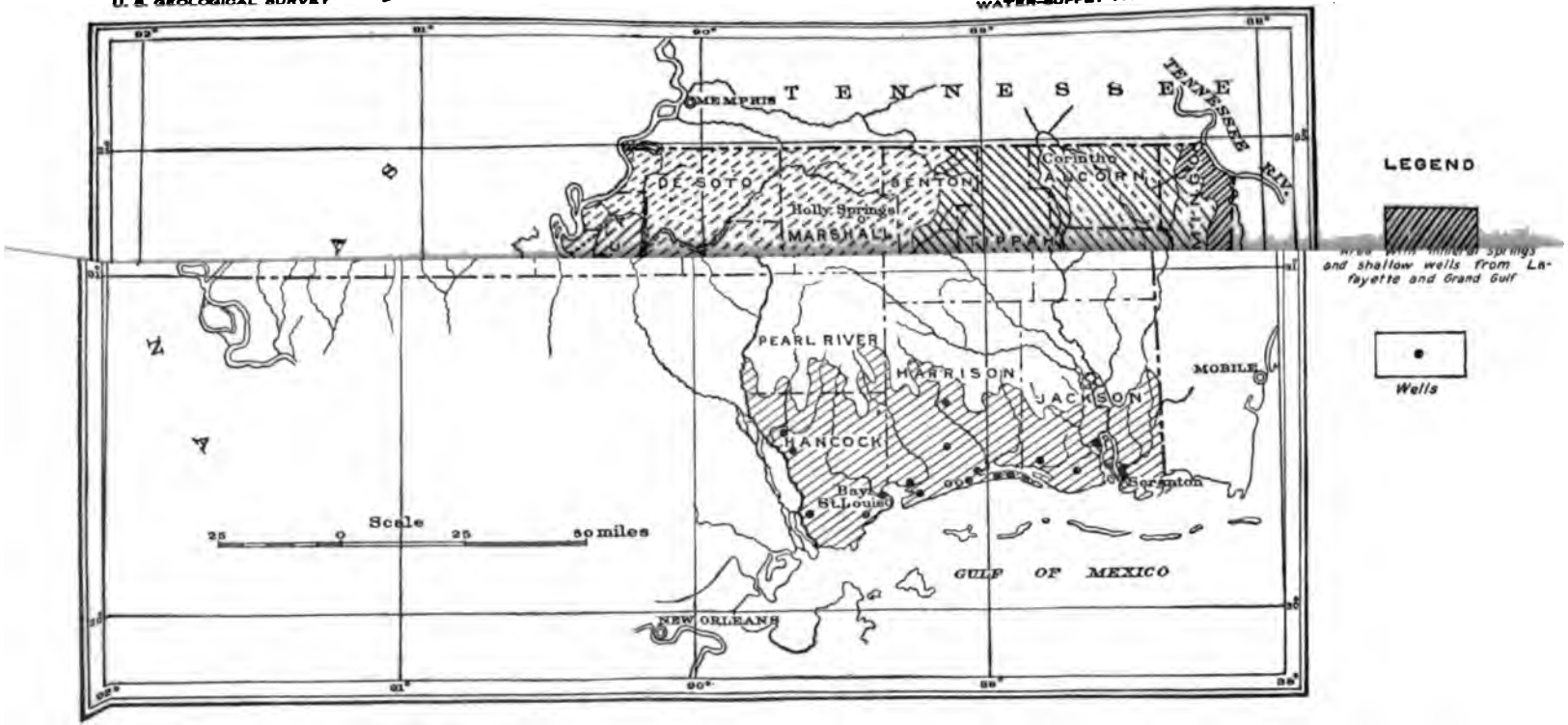


FIG. 11. North-south cross section from Scranton to Tennessee River. L, Quaternary (silts); K, Grand Gulf; J, Vicksburg; I, Jackson; H, Claiborne; G, Tallahatta; F, Wilcox; E, Sucarnochee; D, Selma; C, Eutaw; B, Tuscaloosa; A, Paleozoic.

laminated clay to cross-bedded sands. Because of the changeable character of these formations we have considered the Tuscaloosa and Eutaw as forming one artesian-water horizon.

Catchment area.—The outcrop of the sands receiving waters of the Tuscaloosa-Eutaw horizon covers about 2,000 square miles, including practically all of Tishomingo and Itawamba counties, the eastern portions of Alcorn, Prentiss, Monroe, and Lowndes counties,



ARTESIAN-WATER MAP OF MISSISSIPPI.

Miss., and Pickens, Lamar, and portions of Marion and Franklin counties, Ala. The region where the water-bearing sands come to the surface is largely in the hilly districts east of Tombigbee River. In the southern portion of the catchment area the elevation is sufficiently high to force the water to the surface over a large area lying to the west. The catchment area from southern Tishomingo County to Tennessee is but little above the territory lying west and the result is that it is impossible to get strong flowing wells north of Baldwyn. However, plenty of good water is obtained near the surface and there are flowing wells along the lower streams to the east.

Upper confining stratum.—In an artesian basin it is necessary to have at least a confining stratum of relatively impervious material above the water-bearing sands. If there is not a confining bed below these sands the water will fill them and the underlying porous rock until a point is reached where the rocks are nonporous.

The overlying Selma chalk contains in its lower part a large amount of compact clay, which forms an impervious layer and prevents the water in the Tuscaloosa-Eutaw from escaping upward. There are areas, however, in the western region of the Eutaw where it is possible to get artesian wells. In these areas there is in the upper part of the Eutaw formation a bed of clay which is sufficiently thick to confine the water below. Farther west the water is under greater pressure and the Eutaw clay bed perhaps loses its compact character, so that the water rises to the base of the Selma chalk and overflows the surface wherever the Selma is penetrated.

Inclination of the beds.—The dip of the strata in the Tuscaloosa-Eutaw horizon varies from a westward dip of about 15 feet to the mile in the north to a south-southwest dip of 35 to 40 feet to the mile in the south. With such a steep dip the water-bearing sands soon pass beneath the overlying strata, and the greater the distance from the outcrop the more difficult and expensive it becomes to reach the artesian waters.

Area of available artesian water.—The westernmost location getting its water from the Tuscaloosa-Eutaw horizon is Starkville. The deepest well here is 1,000 feet, and the water rises to within 154 feet of the surface. Starkville is near the west outcrop of the Selma formation, in which it is impossible to get good water; but fortunately, it can be obtained over the entire area by drilling through the Selma into the Tuscaloosa-Eutaw. It must not be expected, however, that flowing wells can be obtained over the entire area. They are limited to the eastern half of the Selma prairie, extending from about the northern boundary of Lee County south to Noxubee County.

There are often erroneous ideas among well drillers and those unacquainted with the laws governing underground waters. One of the commonest is that, by going deep enough, flowing wells can be obtained anywhere. The Tuscaloosa-Eutaw is the lowest known water horizon in Mississippi, and it would be impossible to get flowing wells from this horizon west of the Selma prairie region. There are no doubt places west of the prairie region where the surface is lower than the head of this water horizon. The question may be asked, "Why can not flowing wells be obtained west of the Selma under such conditions?" But allowance must be made in this, as in all other horizons in the State, for the friction the water encounters in passing through the porous medium. The possibility of getting flowing wells decreases as the distance from the head increases. Another obstacle is the great depth of the water below the surface. If the surface dip of 30 feet to the mile continues to the west, at a distance of 100 miles from the head of the water it would require a well 3,000 feet deep to reach the water horizon.

RIPLEY HORIZON.

In going westward from the Tuscaloosa-Eutaw outcrop, or upward in the geologic column, the next artesian-water horizon encountered is a small area receiving its water from the Ripley formation. The entire area of this formation occupies approximately 600 square miles, including a small portion of Chickasaw, Pontotoc, Union, Tippah, and Alcorn counties. It includes a long triangular belt having a maximum width of 18 miles in Tippah County and forming an apex near Houston.

Catchment area.—The water of the Ripley occurs in the lower portion of the formation, which is made up of alternating strata of limestone, marl, and sand. The water-bearing strata come to the surface in the hills near the eastern border of the Ripley outcrop—that is, along the western slope of the Pontotoc divide. The country slopes westward and is drained by Tallahatchie River and its tributaries.

Upper confining stratum.—The alternating beds of sandstone, clay, and limestone of the Ripley are overlain by the heavy-bedded, compact clay of the Porters Creek formation. This clay is impervious, and confines the water in the Ripley.

Dip of the water-bearing stratum.—No accurate measurements have been made of the dip of the Ripley sands. There is but one line of wells which get their supply of water from the Ripley, and these wells are about parallel to the strike of the strata. Farther west the Wilcox has been found to have a westward dip of about 16 feet per mile, and the Selma chalk to the east has a westward dip of 10 to 15 feet per mile, so that we can assume that the inclination of the Ripley is about 12 to 15 feet per mile.

Area of available artesian water.—Flowing wells have been obtained from the Ripley horizon only along upper Tallahatchie River and some of its upper tributaries. A large number of wells have been drilled in the vicinity of New Albany and Ecru. When the first ones were drilled at New Albany, the water rose 20 to 30 feet above the surface, but the increasing number of wells soon lowered the head, and they now have to be pumped.

The writer observed for six hours the pumping of a new well at Ecru. The depth was 93 feet, and the water, when the well was completed, barely rose to the surface, as it does in the other wells in the town. After six hours' pumping with a Cook pump drawing 120 to 130 gallons a minute, the other wells in town were lowered 3 feet. This indicates that they all derive their water from the same source and that the supply is limited.

Efforts have been made to get flowing wells at Pontotoc and other places south to Houston, also at places north of New Albany, but without success. The reason is not far to seek. The elevations of Ecru and New Albany are 374 and 381 feet, respectively. At these places the water barely reaches the surface, which indicates that the head is but little above these elevations. From Cherry Creek to Pontotoc the elevation rises from 375 to 478 feet. Pontotoc is located on the crest of Pontotoc divide, and there is no higher land to the east to supply artesian water; it is therefore impossible to get flowing wells at that place. From New Albany to Ripley the elevation rises from 381 to 525 feet, thus getting above the water head to the east. The only place where flowing wells from this horizon can be expected is down Tallahatchie River, and perhaps along the headwaters of Tippah Creek in western Tippah and eastern Benton counties, and in northeastern Calhoun County, along Shooner River.

WILCOX HORIZON.

The extensive outcrop of the Wilcox formation covers 8,000 square miles, including approximately the counties of Benton, Lafayette, Yalobusha, Calhoun, Webster, Choctaw, and Winston, and the larger portions of Kemper and Lauderdale counties. Only the lower division of the formation is included in the water-bearing horizon.

Catchment area.—The porous sands and sandy clays which come to the surface in the eastern half of the area and lie between the water-tight beds of the Porters Creek and the belt of clays used for stoneware at Holly Springs and Oxford make up the Wilcox artesian-water horizon. The catchment area is largely covered by the Lafayette sands, which offer but little obstruction to the absorption of the rainfall, and a large amount sinks quickly into the underlying strata.

Upper confining stratum.—The stoneware clays of Holly Springs and Oxford, which form a narrow belt of country about the middle of the formation, extending from the Tennessee line south in a semicircular direction into Alabama, form the upper confining stratum of this horizon. These clays change from a white or gray color in the north to a chocolate-brown in the central and southern areas.

Dip of the water-bearing strata.—An east-west line of wells extending from Oxford to lelen gives the following data for determining the dip of the strata, if it is assumed that ie water comes from the same source:

The elevation of the well at Oxford is about 450 feet. Water was obtained here at a epth of 100 feet, or 350 feet above sea level. In the Batesville well, water was struck at 35 feet, or 51 feet above sea level. This gives a difference of 401 feet in the elevations f the water horizon. The distance between Oxford and Batesville is 24 miles. By dividg 401 by 25 we obtain the dip of the strata, which is over 16 feet to the mile. Similar lculations between Batesville and Belen give a dip of 17 feet to the mile, and between atesville and Riverside a dip of 18 feet to the mile. We can therefore assume a westward ip in this region of 16 or 17 feet to the mile.

There are but few data for determining the dip to the south in the southern part of the ormation. However, we know from the underlying and overlying strata that the dip is much reater to the south than to the west.

Area of available artesian water.—The area underlain by the Wilcox sands and sandy lays includes the entire State west and south of their outcrop; but the inclination of the eds soon carries the water-bearing strata below the reach of the drillers. Two causes end to make flowing wells more easily obtained west of the source than south: (1) The nore gentle westward dip keeps the water nearer the surface, while the dip to the south soon carries the water horizon beyond reach; (2) the elevation of the surface lying west decreases and reaches a lower level than that to the south.

The flowing wells in the Yazoo Delta north of Leflore County obtain their water from the Wilcox. South of this area water is found in a different horizon. In the western and southern portions of the delta the distance from the source has become so great that the water fails to reach the surface on account of the friction it encounters in passing through the sands. There is but a small area outside of the northern part of the delta where flowing wells are obtained from the Wilcox horizon. Those at Water Valley and Coffeeville, many in Lauderdale, and a few in southeastern Newton, and perhaps in northern Clarke County, get their waters from the Wilcox.

CLAIBORNE HORIZON.

We have considered the white and chocolate-colored stoneware clays near the middle of the Wilcox formation as the division between the Wilcox and Claiborne water horizons. They form the upper confining beds of the Wilcox and the lower confining beds of the Claiborne. If there were a water-tight bed at the top of the Wilcox, there would be two vater horizons belonging entirely to this formation; but, since this upper impervious bed s wanting, we should consider the sands and sandy clays above the stoneware clays as a art of the Claiborne formation.

Catchment area.—Besides the area of the upper Wilcox the catchment area of the Claiorne includes a belt from 12 to 40 miles wide extending from Grenada County southsutheast through Carroll, Attala, Leake, southwestern Neshoba, Newton, Lauderdale, and larke counties. The belt is narrowest near the Alabama line and widest in Leake County. he outcrop of the strata of the Claiborne horizon includes beds of unconsolidated micaous sands, sandy clays, and more or less coarse-grained micaceous sandstone. There is the Tallahatta buhrstone at least one horizon of very compact quartzose sandstone. All the Tallahatta, with the possible exception of the quartzose sandstone, is capable of olding a large amount of water in saturation. Over much of the area the Lafayette overs the surface. Along many of the streams and hillsides the Lafayette has been moved by erosion and the porous sands and sandstones of the underlying formations are posed. Besides the direct absorption of the rainfall into the porous strata there are a umber of streams which lose a large amount of their waters in passing over the inclined ges of these strata. The water sinks quickly into the open-textured sands, and many of e smaller streams flow but a short time after even a hard rainstorm. This is particularly

true along the upper courses, where the streams have not silted up their beds with impervious clays. The absorption is greater in summer than in winter.

Upper confining stratum.—The upper confining stratum of the Claiborne horizon consists of a series of "soapstone" and pipe-clay beds which belong to the basal part of the Lisbon formation. Well drillers say that in places flowing water is found just beneath a very hard "flint" or sandstone, which is perhaps the quartzose sandstone of the upper Tallahatta.

Dip of the water-bearing strata.—The dip of the strata to the west, as shown in the well records between Winona and Indianola, is as follows: If the waters derive their supply from the same source, there is a dip in the water horizon between Winona and Greenwood of 18 feet to the mile, though one well at Greenwood would give a dip of only 10 feet to the mile; the dip between Greenwood and Ittabena is 20 feet to the mile; between Ittabena and Indianola 35 feet to the mile.

The well at Jackson gets its water at a depth of 1,168 feet. The elevation of the top of the well is about 280 feet above sea level. Estimating the head of the water supplying the well to be 100 feet higher than the surface at Jackson and the distance from the source to the well to be 50 miles, we get a dip of the water-bearing sands of 25 feet to the mile.

Various estimates made from records of the wells along Chickasawhay River give a southward dip of the water horizon of from 10 to 20 feet to the mile.

Area of available artesian water.—The area of accessible artesian water coming from the Claiborne horizon includes the larger part of the Yazoo Delta lying south of a line running from Grenada to Rosedale, and the central prairie belt extending from Yazoo to Waynesboro, on Chickasawhay River.

The area of flowing wells occupies a much smaller territory. In the delta it includes Leflore County, the larger part of Sunflower County, and the northern part of Holmes County. West of this the water encounters too much friction to give good flowing wells. A well 1,567 feet deep at Yazoo failed to obtain a strong flow. The city well at Jackson is perhaps the most distant one receiving its water from the Claiborne horizon. This well is 1,168 feet deep and gives a strong stream. The water is highly impregnated with minerals and too warm to be palatable for drinking. There are numerous flowing wells along Chickasawhay River, from Waynesboro to near Decatur, in Newton County; those south of Enterprise receive their waters from the Claiborne horizon.

PASCAGOULA HORIZON.

Immediately underlying the Grand Gulf formation is a series of older Miocene beds which outcrop along Chattahoochee River in Florida and also along Conecuh River in southern Alabama. From fossils collected by Mr. Johnson along Chickasawhay River a few miles above the mouth of Leaf River it has been shown that there is a horizon here bearing a fauna which is much older than the Vicksburg. He has called the beds Pascagoula, and refers them to the Miocene. It has not been conclusively proved that the Pascagoula is the same horizon as the Chattahoochee beds, but the fossils which were collected have been referred to the Miocene. It is quite probable that many of the deeper wells along the coast derive their supply of water from the Pascagoula, but as the formation has been recognized only along the Pascagoula River nothing is definitely known about its water-bearing capacity.

GRAND GULF HORIZON.

But little detailed geologic work has been done over a large part of the Grand Gulf area from Jackson to the Gulf, and the character of the water-bearing horizons is known only in a general way. The southern counties of the State are covered deeply by two great surficial formations, the Grand Gulf and the Lafayette. The great well at Rose farm and another at Wilson Springs, north of Moss Point, demonstrate that there is another important water horizon underneath the Grand Gulf. The greater part of the wells along the coast find flowing water at 500 feet, more or less, and many toward the west at 300 feet and lower. None of these flow with the great pressure of the deeper wells, nor do they furnish so great a supply. From only one of the shallower wells have fossils been obtained—that at Logtown, on Pearl River—but as yet they are undetermined.

Mr. L. Sutter, one of the most skillful and observant drillers of the coast, says that there are four distinct artesian water-bearing strata on the coast. This does not include the one immediately under the alluvial sands at a depth of 100 to 200 feet, which sometimes flows and sometimes does not. One horizon is reached at about 300 feet from which water occasionally rises to the surface; a second at 400 to 500 feet often gives a strong flow, and the majority of owners are content to stop here; a third is at 600 to 700 feet, in which there is generally gravel and a good flow of water; the last flow comes from a depth of 800 to 1,000 feet, and has a strong pressure and abundant supply.

The lowest member of the Grand Gulf formation is a bed of impervious clay about 75 feet thick. Resting on the clay is a series of sandstones alternating with grayish and often lignitiferous clays. These sandstones and open clays form the water-bearing strata of the Grand Gulf.

Catchment area.—The sandstones and lignitiferous clays come to the surface along the northern area of the Grand Gulf formation. In the northwestern portion the sandstone is more prevalent than the lignitiferous clays. It alternates with thin strata of gray clay, as is shown at Star and Raymond, and in various places in southern Rankin, Hinds, Simpson, Copiah, and Claiborne counties. Along the northern outcrop of the Grand Gulf in the eastern part of the State the sandstone is wanting. The strata here are lignitiferous, sandy clays containing leaf impressions and often fragments of lignitized wood. But the material is porous enough to absorb a large amount of water, which is easily recognized by its character when it again comes to the surface. The large amounts of gypsum and common and magnesian salts, the small quantities of iron pyrite, and the decayed vegetable matter render the water in places unsuitable for drinking.

Upper confining stratum.—The upper confining beds of the Grand Gulf horizon consist of the extensive clay beds outcropping in the vicinity of Hattiesburg.

Dip of the water-bearing strata.—If the wells at Laurel and Ellisville derive their supply from the same horizon, the southward dip of the strata is about 11 feet to the mile. The dip between Ellisville and Hattiesburg is, according to the data in hand, much less. We have but one well record at Ellisville on which to base our estimates, which are no doubt too small.

Area of available artesian water.—The sandstones and porous clays forming the catchment area of the Grand Gulf horizon soon pass beneath younger deposits. Flowing wells are obtained at Taylorsville, Hattiesburg, Columbia, and along the coast. There is a large area lying north of a line drawn from Leakesville through Hattiesburg, Monticello, Brookhaven, and Natchez, where deep-well water can be obtained at a maximum depth of 800 feet. Flowing wells should be found along the larger streams at a much shallower depth.

Below is a generalized section of wells between Biloxi and Pass Christian. The record was given to G. D. Harris, for his "Underground Waters of Southern Louisiana," by Mr. A. Dixon, a practical well driller of that region.

Generalized section of wells between Biloxi and Pass Christian.

	Depth in feet.
6. Sand	80
5. Clay	125
4. Sand and clay	425
3. Light-gray fine sand	500
2. Clay	600
1. Water-bearing sand	685

It will be seen by consulting the section that No. 2 is a bed of clay extending in depth from 600 to 685 feet, with a water-bearing sand below. No. 1 is no doubt the water-bearing sand belonging to the lower horizon, and the clay of No. 2 is the impervious bed at the top. Some drillers say that the clay coming immediately above the water horizon has a bluish-green color and is often 150 feet thick.

The large number of wells along the coast which draw their supply from this horizon indicates a large catchment area. Those who have flowing wells usually let them flow

at full pressure, the amount of water used being but a small fraction of the amount wasted. Well owners should bear in mind the possibility of overdrawing the supply. New wells are being constantly drilled, and this also tends to lessen the amount for each well. Good water such as that found in the deep wells along the coast is a great blessing to the people living there, and a cessation of the flowing wells would be keenly felt. Fortunately, the supply so far has been adequate for all purposes.

LAFAYETTE HORIZON.

The most recent formation in the State furnishing artesian water is the Lafayette. Over the larger portion of the State it forms a mantle up to 200 feet in thickness resting unconformably upon the older formations. The Lafayette passes beneath still younger strata at a distance of 15 to 30 miles from the Gulf and is found in the coast wells at a depth of 150 to 350 feet below tide. North of the point where the Lafayette passes under cover of the other formations, it forms one of the principal sources of the shallow-well waters of the State.

Catchment area.—Along the Gulf and Ship Island Railroad south of Hattiesburg there are thick beds of coarse sand and fine gravel belonging to the Lafayette. They overlie the bluish-green clays at the top of the Grand Gulf horizon, and are in turn overlain by more recent clays. The surface between these two clay layers forms the catchment area of the Lafayette. It is less extensive than the Grand Gulf horizon, but the material is much more porous and therefore contains more water to the cubic foot.

The elevation of the catchment area is sufficient to force the water to a maximum height of 20 feet above the surface. At a distance of 25 miles from the Gulf the elevation along the Gulf and Ship Island Railroad reaches 250 feet. If this elevation were continuous across the State from east to west, the water in the coast wells receiving their supply from this horizon would rise to a much greater height than it does; but the streams have cut their channels to such a depth that the head of the water is much below this elevation.

Upper confining stratum.—The recent clays along the coast rest unconformably upon the Lafayette horizon, and form its upper impervious stratum. From the various reports of the drillers the coast wells from Scranton to Pearl River strike the Lafayette sands and gravel at from 150 to 380 feet. The upper confining bed of clay is reported to be 35 to 100 feet thick. The following table, compiled from the well records from Scranton to Pearl River, gives some interesting facts relating to the pressure and depth of the wells:

Wells between Scranton and Pearl River.

Locality.	Wells less than 500 feet deep.	Wells with flow less than 30 feet above surface.	Wells more than 500 feet deep.	Wells with flow 30 feet and more above the surface.
Biloxi	7	5	15	17
Gulfport		2	6	4
Longbeach		1	2	1
Mississippi City		3	6	3
Pass Christian	2	7	30	25
Fontainebleau			2	2
Moss Point		2	3	1
Ocean Springs		5	13	8
Scranton			2	2
Bay St. Louis	9	8	4	5
Waveland	7	7		

By comparing the depths with the pressures in the table above, it will be seen that the water coming from a depth less than 500 feet has a different source from that of the water coming from a greater depth. Wells with an approximate depth of 500 feet or more

have a much greater pressure than shallower wells. In most of the former the pressure is sufficient to force the water 30 feet or more above the surface, the maximum height being 80 feet. A well at Bay St. Louis, 250 feet deep, has a greater pressure than any of the other shallow wells, and the height of flow above the surface is 20 feet.

Dip of the water-bearing strata.—By comparing the distance from the outcrop of certain beds with the depth at which they are found in the coast wells, a southward dip of about 15 or 20 feet to the mile is estimated.

Area of available artesian water.—The artesian area of the Lafayette is comparatively limited. Some of the more shallow wells along the coast obtain their waters from this horizon. The entire area of the Lafayette which is covered by later formations is but a few square miles, extending about 20 miles north from the coast and including the southern portions of Harrison, Hancock, and Jackson counties.

NOTES ON WELLS OF MISSISSIPPI, BY COUNTIES.[a]

Adams County.—The surface of Adams County is very irregular. In the eastern part the Grand Gulf formation is overlain by the Lafayette. Near Mississippi River the loess overlaps all the other formations and extends from 5 to 10 miles from the river. The wells of this county derive their waters from two sources. The shallower wells are supplied with soft, palatable water from the base of the Lafayette, and the deeper wells from the sands of the Grand Gulf.

The city waterworks company of Natchez has four wells located near together, 56 feet above the river. An examination of the water from No. 1[a] shows 37½ parts solids to 100,000 parts of water, and a hardness of 7½. Well No. 2 contains 27 grains of solids to the gallon, and shows the presence of a very small number of innocuous bacteria. The log of well No. 4 shows 160 feet of loess, 50 feet of Lafayette, and 220 feet of Grand Gulf material. Well No. 9 is located on the Greenville plantation, 7½ miles from town. There are hundreds of wells of this character in the western part of Adams County, the water generally being obtained at the contact of the Lafayette and the underlying Grand Gulf. The log of well No. 9 showed 12 feet of Lafayette and 85 feet of Grand Gulf, to which the water owes its hardness.

Alcorn County.—The Lafayette has been removed from a large part of the surface of the county, which is a gently rolling plateau sloping in a northwest direction to Hatchee River. When the first wells at Corinth were drilled the water rose to the surface, but was lowered several feet below the surface by additional wells. An effort has been made here to get wells which would flow, but the prospects are not very encouraging, since the source of the water is but little above the elevation of the town. There is a bare possibility of striking an artesian flow in the older, hard rocks at a depth of several hundred feet. These rocks come to the surface in northern Alabama and Tennessee at an altitude sufficiently high to force water to the surface at Corinth. However, the disturbance of these older rocks has caused them to be so folded and jointed that it would be a risk to undertake such a project. The log of one of the Corinth waterworks wells, No. 11, shows 20 feet of Lafayette, 280 feet of undifferentiated Cretaceous, and 45 feet of Lower Carboniferous or Devonian.

Amite County.—No well records were obtained from this county. Flowing wells are not probable.

Attala County.—The only well reported from this county is No. 12, at Kosciusko. In this well two fossiliferous beds of clay were penetrated, the first at a depth of 65 feet and the second at 150 feet. Water first entered the well at a depth of 76 feet and now stands at that level.

Benton County.—All shallow-well water in Benton County is obtained from the Lafayette and Wilcox formations. There is a possibility of getting flowing wells from the Ripley sands along Tippah Creek in the eastern part of the county at a depth of about 400 feet.

[a] A partial list of the deep wells in Mississippi is given in the table on pages 40-59. The well numbers in the text refer to this table.

Bolivar County.—This is one of the Yazoo Delta counties bordering on Mississippi River. The shallow wells receive abundant water from the Port Hudson formation, but it contains much organic matter and is therefore very unwholesome. These shallow wells are made by placing a cap on the end of a pipe, perforating the lower portion, and driving the pipe into the ground. Water enters the pipe through the perforations and is raised to the surface by a pump.

The deep wells reach the Claiborne horizon, but are so far from the head that the pressure is greatly lessened by the friction the water encounters in passing through the sands. In most of the counties of the Yazoo Delta bordering the Mississippi the water fails to rise to the surface.

Calhoun County.—This county is traversed by two large streams flowing west, Yalobusha and Shooner rivers. Between these streams is a narrow divide which rises more than 200 feet above them. On the higher ridges and, in fact, everywhere except along the streams the Lafayette is very thick. At its base is a water supply abundant for all ordinary domestic uses. Wherever possible, this water should be used in preference to the deeper well waters, which in this region are apt to be strongly impregnated with mineral salts.

Carroll County.—Carroll is one of the counties bordering the eastern rim of the Yazoo Delta. Its western part is therefore but little above Yazoo River, and flowing wells are easily obtained. The greater part of the county is in the Claiborne hills, where flowing wells are possible only along the lower streams.

The town of Carrollton, near the center of the county, has a large number of flowing wells. It is situated on Big Sandy Creek and has an elevation of 229 feet above sea level. Well No. 17 was drilled 1,250 feet deep, but failed to get an overflow. The first water from the upper Claiborne, at 300 feet, rose to within 17 feet of the surface. A second stream at 450 feet came within 12 feet of the surface. These water beds were cased off and no further supply was obtained. Water from well No. 18 is delivered by a ram to a tank, from which it is distributed over south Carrollton.

Chickasaw County.—The eastern half of this county is underlain by the Selma chalk and the western half by the Porters Creek and Wilcox beds. The water from the Tuscaloosa-Eutaw horizon will rise to the surface in a narrow strip in the northeast corner of the county. Some surficial waters are obtained from the base of the Lafayette where that formation is present, but the general supply of wholesome water comes from the deep wells which reach the Tuscaloosa-Eutaw horizon. Water from well No. 20 at Okolona is forced into a tank by compressed air and is thence distributed over the town.

Choctaw County.—It is not surprising that no artesian wells are reported from Choctaw County, as the high Pontotoc divide extends through its eastern part. At Blantons Gap, 2 miles east of Ackerman, the Illinois Central Railroad reaches the highest elevation between Durant and Aberdeen.

The only possibility of getting flowing wells in the county would be along Big Black River, on the northern and northwestern boundary. Good surficial water is obtainable from the base of the Lafayette, which is exceptionally thick over this region.

Claiborne County.—Good water is obtained in shallow Lafayette and Grand Gulf wells, but there is no artesian flow.

Clarke County.—Clarke County is one of the Alabama-Mississippi border counties lying along Chickasawhay River. The nearness to the catchment areas of the Claiborne and Wilcox formations and the large area of low-lying territory along the Chickasawhay cause many artesian wells. The county is crossed by the Lisbon beds, the Tallahatta buhrstone, and the Jackson formation, while the upper Wilcox crosses the northeast corner, and the Vicksburg the southwest corner. The Lafayette is also very thick back from the larger streams.

Well No. 22, at Barnett, was started in the Jackson marls, which were 65 feet thick. Water was obtained in the sands immediately underlying, and again in sands at 125 feet. At a depth of 350 feet all the water left the well and passed off through the sands at that point. The well was cased for 150 feet. In well No. 23, also at Barnett, water was obtained

t 65 feet and rose 25 feet in the well. At 125 feet another stream was struck which rose to within 20 feet of the surface. As in well No. 22, all the water was lost in the sands at a depth of 350 feet. None was found below that level.

Well No. 24, at De Soto, begins near the top and ends near the bottom of the Lisbon beds. The water has a reddish color like other water coming from this horizon.

The town of Enterprise has two wells (No. 25) about 100 yards apart and of the about same depth. They are affected by a large well drilled at a sawmill a few hundred yards north. The log from well No. 26 showed 22 feet of Lafayette. When first drilled this well had a weak flow. Three other similar wells, from 175 to 200 feet in depth, are located in the neighborhood. Well No. 29 is on the west side of the river and on higher ground than those above mentioned. The Lafayette is here very thin and is underlain by a 10-foot Claiborne shell bed. When the mercurial barometer is high the well flows, but usually it has to be pumped.

About 15 wells have been bored in the town of Quitman. The log of well No. 31 showed 40 feet of Lafayette, 40 feet of Lisbon, 150 feet of Tallahatta buhrstone, and 2 feet of Wilcox. The volume of water has been lessened by the large number of wells. Some of the larger wells used for supplying water for the Mississippi Lumber Company are pumped by compressed air. During the pumping the flow of other wells in the town is either decreased or stopped. Well No. 33 was the first one drilled in Quitman. The flow has been much reduced by the drilling of other wells. The Lafayette in this well was 30 feet thick. To the east in the hills the Lafayette is from 40 to 100 feet thick.

Well No. 34 is the public well at Shubuta. A weak overflow of clear water was obtained at a depth of 175 feet, but the main flow is from 400 feet and is a red water, which is alkaline in character and carries 62 grains of sodium bicarbonate to the gallon. Sixteen flowing wells and 1 nonflowing are reported from the town of Shubuta, and they range in depth from 165 to 422 feet. The maximum height to which the water rises above the surface is 30 feet. There are two distinct water horizons in the Shubuta wells, both of which yield highly alkaline waters. The first horizon, at 165 to 175 feet, yields a clear alkaline water with a pressure sufficient to raise it to a maximum height of 15 feet above the surface. The second horizon, at about 400 feet, yields a red alkaline water which is typical of all waters coming from the uppermost Lisbon beds. The pressure from this level raises the water 20 to 30 feet above the surface. Well No. 43 is 1 mile east of town, on low ground near the river. Well No. 45 is 2½ miles north of town.

Clay County.—The whole surface of Clay County is underlain by the Selma chalk, except a narrow strip 2 to 5 miles wide along Tombigbee River on the eastern border. Over the entire country the water from the Tuscaloosa-Eutaw horizon will rise in wells to within a few feet of the surface. In some localities in the eastern part the water flows over the surface.

The drill in well No. 52 at West Point penetrated more than 500 feet of the Selma, beneath which an unusually pure water was obtained. This well has a weak but steady flow. Later wells, however, have lowered the height of the water.

Coahoma County.—The artesian wells from this part of the Yazoo Delta get their flow from 700 to 1,000 feet below the surface. There is a marked difference in the pressure and quantity of water in some of the wells.

At the town of Clarksdale the city well (No. 53a), which is 876 feet deep, flows a very weak stream of 3 gallons per minute. The well at Lyon (No. 55), only 2 miles north, is 975 feet deep and flows a strong stream of 22 gallons per minute. This well, however, obtains its water from the 970-foot level, which is 94 feet lower than the Clarksdale well. No doubt the latter would strike the same water at the depth of the Lyon well. An analysis of the water from well No. 55 shows 3774.6 parts per million of solids, of which 2738.9 parts are sodium carbonate.

Copiah County.—This county is in the region of the Grand Gulf formation, which is in places deeply covered by the Lafayette sand and gravel. A high ridge extends north and south across the county, separating the waters of the Pearl on the east from those of the Mississippi on the west.

Water was obtained in well No. 56, at Wesson, at a depth of 120 feet in the lignitic clay of the Grand Gulf. It was so highly impregnated with vegetable matter and alkalies as to be unfit for drinking purposes. It is stated that a boring 1,100 feet deep near Wesson failed to obtain water. The drinking water in this locality is obtained from wells at the base of the Lafayette.

Covington County.—The well waters from Covington County come principally from the lower members of the Grand Gulf. There is more or less mineral matter in the water, often rendering it undesirable as a constant drinking water.

De Soto County.—The log of a well in Hernando shows the following relations: Flint gravel 45 feet, yellow clay 20 feet, brown shale 25 feet, light-brown shale 55 feet, hard shell or hardpan 1 foot, light-gray shale 24 feet, and sand 50 feet.

The well was made in sand, is 10 inches in diameter, and has a capacity of 150 gallons daily. Water is raised by a deep-well pump and stands 20 feet below the surface. The quality is about like that of the Memphis water.

Franklin County.—Shallow wells are obtained in Franklin County from the Lafayette and Grand Gulf. Artesian wells are not possible.

Greene County.—Artesian wells may be obtained along Chickasawhay River, in the eastern part of the county. There are as yet no records of any deep wells in this county, perhaps because of the small population.

Grenada County.—Grenada County is cut from east to west by Yalobusha River. Along the lower course of the river on the eastern edge of the Yazoo Delta there are numerous artesian wells.

The town of Grenada is supplied by deep-well water, which is pumped to a large standpipe on a hill about 1 mile from town and from there distributed over the city through pipes. The hill on which the standpipe is located is about 150 or 175 feet above the city and a strong pressure is thereby obtained.

Hancock County.—Hancock County is the most western county bordering on the Gulf. The drainage is toward the south and southwest. The geologic formations belong to the post-Tertiary period. The region of flowing wells includes a strip along Mississippi Sound 5 to 10 miles wide and likewise the region along the Pearl River bottom on the west side of the county.

Twenty-three wells are reported from this county. The temperature of the deeper wells is reported to be 78°. Notes on some of these wells are given below. The numbers correspond with those in the table (pp. 42–45):

No. 57. This well has no strainer at the bottom and became clogged, its flow diminishing from 5 gallons per minute to nothing. After partly cleaning, a flow of 15 gallons per minute was obtained but this has now decreased to 8 gallons.

No. 58. This second college well is located 1,000 feet from the first. The original flow was 60 gallons per minute, but the well later became entirely clogged. A flow of 5 gallons is now obtained.

No. 59. Abundant gravel, similar to that on Bayou de Lisle, 10 miles northeastward, was found at 40 feet, while at from 175 to 300 feet univalve and clam shells were found.

No. 60. This is one of the shallowest wells at this point. There are some fluctuations of flow of the shallower wells, thought by drillers to be connected with tidal fluctuations.

No. 61. This is one of the best wells at Bay St. Louis. The water is used in a canning factory. A cypress log was encountered at 90 feet, and many fossil shells at 200 feet.

No. 62. In the winter of 1893-94 this well ceased to flow, but began again in the spring and has continued ever since. The flow fluctuates a little with the tide.

No. 63. Fossil shells were found at 170 feet, but none were preserved.

No. 64. This well is 16 feet above tide level. It flows at high tide, but not at low. During storms which raise the water level the flow is greatly increased.

No. 65. This well does not ordinarily flow, but during storms which raise the water of the Gulf it flows freely.

No. 66. Rotten wood, apparently cypress, was encountered at 100 feet and gravel at 190 feet. Water was found at this point, but the well was continued to the second water-bearing stratum at 420 feet. The gravel resembles that at Bayou de Lisle, 10 miles northeast.

No. 67. A good water horizon was passed through at a considerable distance above the one from which the supply is now obtained.

No. 69. This well is located on Bayou Tally, several miles north of town. Fossil shells were found at 40 feet, but none were preserved.

No. 71. Three sources of water were found—one under the Port Hudson, one under the Lafayette at) feet, and one near the top of the Grand Gulf at 225 feet.
No. 73. The elevation of this well, like practically all of those at Waveland, is 16 feet above tide. This the shallowest well at Waveland, the well stopping at the first water-bearing horizon.
No. 74. Water was obtained at 320 feet, but was supposed to be insufficient, and the well was con-nued 40 feet into the clay.
No. 75. The stratigraphy shown by the wells in Waveland is similar to that at Bay St. Louis.
No. 76. West of Bay St. Louis.
No. 78. This well was continued into the clay several feet below the water-bearing sand.

Harrison County.—This county offers a diversity of topographic features. The southern art, bordering on Mississippi Sound, is but a few feet above tide. Twenty-five miles from e coast the Gulf and Ship Island Railroad reaches an elevation of 270 feet, while the hills) the west rise perhaps 100 feet higher. At the northern edge of the county the railroad aches 305 feet elevation. These high hills furnish the outcrop of the geologic formations hich supply the high-pressure wells along the coast. The entire coast in the southern art of the county is perforated by wells, some of which will force the water 80 feet above e surface with a flow of 450 gallons per minute.

In well No. 102 fossil shells were found at 340 feet, but none were saved. The well pplies a large sawmill and furnishes water for the village of Delisle.

The wells at Pass Christian (Nos. 122-153) are about 16 feet above tide and all have a rong flow, which increases with depth. The supply of the deeper wells appears to come om fossiliferous beds which Mr. L. C. Johnson has referred to the Pascagoula. The water om the shallower wells comes from one or all of the three water-bearing sands above e so-called Pascagoula. The temperature of wells 700 feet deep is 71°.

Hinds County.—The waters of the eastern part of Hinds County flow to Pearl River and ose of the western part to the Big Black. It is difficult to obtain good drinking water in e Jackson and Vicksburg formations, which underlie the surface in the northern part of e county. More than half of the southern part is underlain by the Grand Gulf formation, hich is here represented by white to gray sandstone, interbedded with sandy clays and nconsolidated sands. The Lafayette covers the surface of the entire county except in nall areas.

The high bluffs along Big Black River are covered with loess, which overlies all the other rmations. It gradually thins out to the east, becoming so closely blended with the yellow am that the two are inseparable. The transition zone will stand erosion better than the mixed yellow loam. Most of the water in this county is obtained in shallow wells, which rive their supply from the base of the Lafayette.

There are four flowing wells in Jackson. The city well is located on the bank of Pearl iver, not far from the wagon bridge. The well is 1,168 feet deep and flows a strong eam of strongly alkaline, warm water. It is so highly charged with minerals that it is t used for any purpose. The source of the water is perhaps the upper Claiborne. The mperature of one of the Jackson wells, 774 feet deep, is reported by Darton to be 74°.

The deepest well (No. 157a) in this section is at Bolton. At a depth of 1,020 feet a fine eam of excellent drinking water was obtained, which rose to within 80 feet of the surface. e well was continued to a depth of 1,517 feet, but no further streams were obtained. At lepth of 1,080 feet the first rocks were found. They occurred in bands 1 to 5 feet thick the bottom of the well.

Holmes County.—The topography and stratigraphy of Holmes County is very similar to at of Carroll on the north. It contains a high north-south ridge near the center and two r-lying regions on either side. In both of these low areas are numerous artesian wells riving their waters from the Claiborne horizon.

Water was first obtained in the well at Pickens (No. 159) at 160 feet, but it was of poor ality. An analysis of the water from the Tchula well (No. 160) shows it to be too alkaline boiler purposes.

Well No. 162 is located in Attala County, 1 mile from West. It is cased down to solid k of the lower Tallahatta at a depth of 100 feet. The water comes from beneath the hard k.

Issaquena County.—Issaquena is a small county bordering on Mississippi River in the southern part of the Yazoo Delta. The surface formations are recent river deposits and Port Hudson, both of which furnish plenty of surficial waters of a poor quality. The region is too far removed to get flowing wells.

Itawamba County.—The Tuscaloosa sands furnish a large amount of fine water over the entire county. There are numerous springs in the western part of the county which issue from just above lignite seams and clay beds belonging to the Tuscaloosa. No doubt flowing wells could be obtained along Tombigbee River, but none are reported.

Jackson County.—The eastern and western parts of Jackson County rise to an elevation of about 300 feet. The central part along Pascagoula River is but a few feet above tide. Like the other two coast counties, the southern part of Jackson has a large number of flowing wells. Twenty wells are reported from Jackson County, and the following notes are given in addition to the data in the table (p. 48–51):

No. 163. Fossil shells were found at 640 feet.

No. 164. Fossil shells of the Pascagoula were found at 500 feet. The formation is here probably about 100 feet thick.

No. 166. This well goes 300 feet below the base of the Pascagoula, assuming the latter to have its normal thickness. It does not, however, reach the Jackson or Vicksburg formations. Mr. L. C. Johnson considers that it may end in the Chickasawhay Miocene beds.

No. 167. This well was bored for oil. At 680 feet it passed through a thin bed of gray sandstone, probably at the base of the Grand Gulf. The water at this level was of a brownish color and flowed [illegible] gallons to the minute, but was cased off. Woody matter was encountered at 720 feet. The well is located 4 miles north of Moss Point.

No. 168. Most of the city is supplied from this well.

No. 171. The water of wells of this depth is better than that from the deeper wells.

No. 177. The horizon of the water bed is fixed by fossils.

No. 178. This well is used for irrigation.

No. 179. This well was begun for oil, but was abandoned because of the sticking of the drill. It still flows considerably, although the main water horizon at 900 feet was cased off. Fossils of the Pascagoula horizon were encountered below 900 feet. Some wood, lignite, and pyrite were also found.

No. 180. It is probable that the water supply is from a sand bed 40 to 50 feet above the Pascagoula marl.

No. 182. Fossil shells of the Pascagoula formation were found below 600 feet.

Jasper County.—There are 10 wells reported from the town of Paulding, with an average depth of about 80 feet. The water rises only 10 feet in the wells. At a depth of 90 feet the Jackson marls are reached. Water coming from the base of the Lafayette is reported to be good and soft, while wells bored into the Jackson have hard water. The wells are bored with a hand auger.

Jefferson County.—No wells reported.

Jones County.—The Grand Gulf clays underlie the entire county. The more sandy clays are water-bearing, but the southward slope of the land is so gentle that the water does not rise to the surface except in the southern portion of the county. It rises to within 40 feet of the surface at Laurel (No. 184) and to 20 feet at Ellisville, which is 7½ miles farther south. If the dip of the water horizon is constant, the water should rise to the surface in wells 8 miles south of Ellisville, provided, of course, the elevation is no higher than at Ellisville.

Well No. 186, at Laurel, obtained its first water at 65 feet, and water was found at various levels until the large supply was reached at 370 feet. The well is cased for 250 feet, the lower 20 feet being brass screen.

Water has been obtained at Ellisville at 70 feet, clearly within the Grand Gulf; and again at 500 feet, possibly at the base of the Grand Gulf, but this is not certain. In neither case did the head force the water to the surface.

Kemper County.—In the eastern part of the county deep-well water, perhaps flowing, can be obtained from the Tuscaloosa-Eutaw horizon by penetrating the Selma chalk. In the western part numerous shallow wells are obtained at the base of the Lafayette. In some places, where the Lafayette has been cut through, bold springs of pure, soft water are found.

Lafayette County.—This county occupies the central portion of the Wilcox area. In general there is a thin layer of Lafayette overlain by a thicker mantle of the Columbia loam,

which reaches a maximum thickness of 20 feet. In the eastern and particularly in the southeastern part of the county are numerous outcrops of lignite veins along the streams.

The county is traversed from east to west by two large rivers, the Yocona on the south and the Tallahatchie on the north. The principal water supply is obtained from the heavy-bedded sands in the Wilcox.

Lamar County.—This has recently been formed from Marion County, and the wells are discussed under that head.

Lauderdale County.—The high line of hills forming the divide between the Tombigbee and Chickasawhay basins extends in a southeast-northwest direction across the central part of the county. The Wilcox and Claiborne strata, outcropping to the south and west, form the catchment area for the artesian wells in the southern portion of Lauderdale and Clarke counties.

From well No. 190, at Lauderdale, 35,000 gallons were pumped in a five-hour test. There is some iron in the water, but it can be used in boilers. The drill passed through solid beds at about 70 feet below the surface, presumably Wilcox. In No. 192 water was first obtained at 135 feet, but it was from a bed of lignite and was of poor quality. The well stopped in a soft, yielding clay which caved badly. The water from well No. 194, coming from the Wilcox, is very hard, but is used in locomotives. The well has yielded 7,000 gallons per hour.

Well No. 196, at Meehan Junction, passes through the Tallahatta buhrstone and into the Wilcox sands. Only 60 feet of casing are used.

Well No. 197 was the second well bored in Meridian. The flow is said to be abundant, but the amount has never been measured. It is located near Okatibbee Creek, 6½ miles northwest of the courthouse and on much lower ground. Well No. 199 is the public well in one of the streets. A hydraulic motor pumps a small stream from this well, in which the water is chalybeate. The water from well No. 201 is a mineral water, but is distilled for making ice. The flow is ample for the purpose, some of the water being used for drinking supplies.

Wells Nos. 202 and 203, at Siding, obtain their supply from the buhrstone. The flow is greatly increased by drilling about 20 feet deeper than the buhrstone and putting in a longer strainer, as other wells in the vicinity also show.

Lawrence County.—The only formations outcropping in Lawrence County are the Grand Gulf clays and the overlying Lafayette. Pearl River crosses the entire county from north to south.

The water supply comes from both the Lafayette and the Grand Gulf, but the greater number of wells get their supply from the latter at a depth of 50 to 75 feet. The Grand Gulf water here, as at many other places, is hard, but is considered wholesome. No flowing wells are reported from this county.

Leake County.—Two shallow wells from the Lafayette are reported from Leake County. The Tallahatta buhrstone outcrops in the eastern part and furnishes a large amount of good water, but the supply has not been developed. Flowing wells are possible along Pearl River at moderate depths, particularly west of Carthage.

Lee County.—The Selma chalk forms the surface rock over the western and the Eutaw over the eastern part of the county. The slope of the surface is southeast, or about parallel to the strike of the strata. The artesian waters at Tupelo, Verona, Plantersville, and other places over the county come from the Eutaw sands, which outcrop in the hills to the east.

The first wells at Tupelo were drilled in the town and had a strong flow. Later, however, numerous wells along the near-by creek and at the United States fishery have been drilled at a lower elevation, and the water in the town wells has been lowered below the surface. Water is obtained in the United States fishery at a depth of 325 feet. There are six of these wells, which supply the water for the various fish ponds and for domestic use.

The water coming from the Eutaw contains more or less iron oxide, and where the Selma chalk is not cased off the water is high in lime carbonate. Where the wells are cased to the bottom the water is normally soft and wholesome.

Well No. 210 is near the eastern edge of the Selma chalk. The first water obtained at 125 feet rose to within 10 feet of the surface. The next horizon was at 250 feet and the water rose to within 3 inches of the surface. The last water was at 322 feet and flowed weakly.

Leflore County.—Leflore County borders the eastern edge of the Yazoo delta about halfway between Vicksburg and the Tennessee line. The highest altitude does not exceed 175 feet. In the adjacent county to the east the hills rise to a maximum height of 550 feet. The sands furnishing the strongly flowing wells in Leflore County come to the surface in the Carroll County hills and in those farther east. The conditions are thus very favorable for obtaining a large supply of flowing water. Leflore is one of the counties of the delta where the well drillers will guarantee a flowing well.

In well No. 217, at Greenwood, the first water was obtained at 340 feet, the next at 450, and a third at 600 feet, all of which are utilized by means of perforations in the pipe at the proper points. Hard rock, belonging perhaps to the Tallahatta buhrstone, was reported at a depth of 200 feet.

The following generalized section of the wells in and near Minter City was given by Mr. Feigler, a sucessful driller of this region: Subsoil 10 feet, sand and silt 100 feet, gravel 5 to 60 feet, sand 80 feet, soapstone and pipe clay interbedded with sand to the bottom of the wells, which range from 420 to 690 feet in depth. The quality of the artesian water from this county is considered excellent by those using it.

Below is a generalized section of the wells at Greenwood which receive their water from the Claiborne: Brown clay 20 feet, common sand 130 feet, coarse gravel 130 to 150 feet, gray sand 130 to 160 feet, fine "sea sand" 160 to 190 feet, gray sand 190 to 220 feet, soapstone or clay 220 to 300 feet, sand 300 to 380 feet, dark-brown hardpan 380 to 460 feet, and sand rock for about 20 feet, below which is a stratum of flint rock always about 8 inches thick. Water is found below this rock in dark-green sand.

Lincoln County.—This county, like Copiah, its northern neighbor, contains the elevated watershed between Pearl and Mississippi rivers, extending in a north-south direction near the center of the county. The uppermost bed of the Grand Gulf formation is here an impervious clay which checks the water collecting in the Lafayette and provides a fine supply of a soft, wholesome quality. Wells penetrating the compact clay of the upper Grand Gulf obtain abundant water at various horizons. No flowing wells are reported.

Lowndes County.—Tombigbee River approximately marks the division between the outcrop of the Eutaw sands and the Selma chalk. There are in Lowndes County 140 wells, 15 of which are in the city of Columbus. On the east side of the river they all flow, and on the west side they rise to a convenient pumping height. In the river valley it is necessary to bore only 200 to 300 feet for water. One well at Columbus 400 feet deep is reported to have a temperature of 70°.

Madison County.—Big Black and Pearl rivers form, respectively, the southeast and northwest boundaries of Madison County, and opposite Canton they approach within 16 miles of each other. The divide between the two rivers is quite narrow, with a long slope to the Big Black and a short steeper slope to the Pearl.

A large part of the county lies sufficiently low to have artesian wells. Flowing wells should be obtained anywhere along the Pearl River bottom on the east, and also along the Big Black at a maximum depth of 1,000 feet. At the same maximum depth flowing wells should be obtained anywhere along the Illinois Central Railroad north of Calhoun, with possibly the exception of Davis station, north of Canton.

The fine, wholesome water obtained in the Bolton well at a depth of 1,080 feet can be struck in southwestern Madison County at about 800 feet and less, and in many places it will rise to the surface. At the town of Canton good water was obtained at 460 feet which rose to within 40 feet of the surface. The water in the city waterworks well (No. 226), which is 1,020 feet deep, is called soft, but has a mineral taste and odor. Its temperature is 74°.

Marion County.—Artesian wells are easily obtained in Marion County along the low-lying land adjacent to Pearl River. There are a large number of wells, with an average depth of 425 feet, in and near the town of Columbia. The water is mineralized, containing sulphur, iron, and sodium, but it is considered soft and is used for domestic purposes.

Marshall County.—The high elevation of this county makes it impossible to get flowing lls, except perhaps along Tallahatchie River in the southeast corner. There is, however, abundant water supply for all ordinary purposes in the Lafayette and the underlying ilcox sands.

The Wilcox sands here are often unconsolidated and thus form a natural filter for the rm waters. On account of the porosity of the sand and the readiness with which the ter sinks into the earth, care should be taken in locating wells in the towns and in places ere the surface water is apt to become contaminated. Filtering water is not sufficient to nove from it the typhoid germs.

Monroe County.—The western part of Monroe County is underlain by the Selma chalk, the stern half by the Tuscaloosa, and a narrow strip along Tombigbee River by the Eutaw. e highest part of the county is in the Tuscaloosa, which is the source of the artesian waters the west. The water-bearing sands have a west to southwest dip of about 30 to 35 feet to e mile.

A well near Caledonia (No. 233) had a most remarkable flow, the water rising with such ce that it was found impracticable to put down any casing. Enough sand and clay was shed out to obstruct Buttahatchie River. The well finally clogged itself and ceased to w. Two others of like dimensions were bored by the same owner with similar results.

Flowing wells are obtained along the valley of the Tombigbee at a depth of about 300 feet. the prairie region to the west the water rises to within 60 to 75 feet of the surface but does t flow.

Montgomery County.—The eastern part of Montgomery County marks the eastern border the Tallahatta buhrstone. The hills, however, are not sufficiently high to get flowing lls over the western part of the county. There is a possibility of getting flowing wells in e southeastern part, along Big Black River.

The water from the deep wells in Winona is unusually pure and valuable for drinking purses and for use in boilers. The following interesting log of one of these deep wells (No. 5) was kept by Mr. R. A. Allison:

Log of deep well in Winona, Miss.

	Feet.
il and clay	25
ange-colored sand	10
Blue marl" (?)	40
gnite	5
icksand	15
ack clay	50
arse sand and fair supply of water	10
gnite	10
Blue marl" (?)	35
ne sand	15
ay	10
icksand	60
ay	40
ne sand, coarse on top	25
own clay	35
arse, water-bearing sand, with gravels at top	27
Total depth	412

The temperature of the water is 65° F. The 50-foot bed of black clay beginning at a depth 95 feet below the surface is the heavy bed of black clay at or near the top of the Wilcox. the town of Grenada, 24 miles north of Winona, the black clay shows in the bank of Yalosha River. At the top of the high hill 4 miles west of Grenada the hard quartzitic sandone of the Tallahatta forms the cap rock. The same Tallahatta buhrstone is found in the ls west of Vaiden. The heavy bed of black clay coming at or near the top of the Wilcox n be traced from Winona, Miss., in well sections and outcrops to Memphis, Tenn.

Neshoba County.—No artesian wells have been reported in Neshoba County. Good shalv-well water is obtained in the Lafayette, while water at a greater depth may be had at the se of the Claiborne in the southwestern part of the county.

Newton County.—There are five different geologic formations represented in Newton County. The Wilcox and Tallahatta buhrstone are in the northeastern portion, the Lisbon beds in the center, and the Jackson calcareous clays in the southwest. The Lafayette overlies all these formations.

There are a number of flowing wells in the southeast corner along Chickasawhay River, which obtain their supply from the buhrstone. At the town of Chunkey the wells are cased only to the buhrstone, which in well No. 238 was at 16 feet.

An analysis of the water from well No. 242, at Hickory, shows the principal mineral ingredients to be sodium, calcium, and magnesium bicarbonates, but the water is not decidedly alkaline.

Noxubee County.—The greater part of the surface of Noxubee County is a rolling prairie sloping southeastward to Tombigbee River. Flowing wells are obtained along the valleys of Tombigbee and Oaknoxubee rivers. Over the remaining part of the Selma prairie water will rise to within good pumping distance of the surface. Mr. Ladd, of Macon, who has been in the well business for fifty years, reports that water will in general rise to an altitude of 218 feet above sea level in this region. The dip of the beds is reported to be 25 feet to the mile southwestward.

The water from well No. 249, at Macon, is alkaline and gives trouble in the boilers if used when fresh, but after standing it can generally be used.

There are three wells (No. 250) on the farm of Mr. Dent, 10 miles east of Macon, which average 650 feet in depth, and nearly every plantation has one or more.

Oktibbeha County.—The western border of the Selma prairies is in the central part of this county. The Porters Creek clays and Wilcox formation come to the surface in the western half. The Lafayette covers but a small part, chiefly in the west. The great thickness of the Selma, which is barren of water, makes it difficult to get good water. Artesian water is obtained in the northeast corner at a depth of about 300 feet. At Starkville, 11 miles southwest of Muldrow, water is obtained at a depth of 900 feet, which shows a westward dip of the strata of 33 feet to the mile. The water in the Starkville well (No. 253) rises to within 130 feet of the surface.

Well No. 254, at the Agricultural and Mechanical College, has a 100-foot Cook strainer The first water was from a 50-foot bed of sand, beneath which is a stratum of clay 10 feet thick, and a layer of sand 35 feet thick. The strainer extends through both water-bearing strata.

Panola County.—The high hills of the Wilcox formation occupy the eastern part of Panola County, and the low-lying Port Hudson sands and clays the western part. The source of the artesian water is the Wilcox sands, which outcrop in the hills east of Oxford. The Port Hudson here, as at all other places in the Yazoo Delta, furnishes a large supply of impure surficial water.

The only flowing wells reported are in the town of Batesville. The city well (No. 255 flows a strong stream of water which has stained the pipe and trough with iron oxide. I is used for general domestic purposes and is considered a wholesome drinking water.

Pearl River County.—The population of this county is very small and the water resource are undeveloped.

Perry County.—Perry is one of the few counties of southern Mississippi, except the Gu coast counties, which have artesian wells. A large number of flowing wells, ranging depth from 325 to 380 feet, have been drilled in and near Hattiesburg. Very little effo has been made to get flowing wells in other portions of the county. In the eastern pa along Leaf River and its northern tributaries, flowing wells should be obtained at about tl same horizon as those at Hattiesburg.

The town of Hattiesburg is supplied with water from flowing wells, one 4 inches a another 6 inches in diameter, the water being pumped from a reservoir through the tow This water is alkaline and chalybeate.

Pike County.—In the greater part of this county the Lafayette lies deep on the Grai *Gulf clays.* Wherever the former is cut through by erosion large springs occur.

Pontotoc County.—The uppermost formation of the Cretaceous comes to the surface in the eastern part of Pontotoc County, and the lower Tertiary appears in the west. The Ripley sands are water bearing. Along the headwaters of Tallahatchie River, in the north-central part, flowing wells are obtained. Over the remainder of the county the elevation of the country lying west of the catchment area of the Ripley sands is too great to get flowing wells, except, perhaps, along the headwaters of Shooner River, in the southwestern part.

Efforts have been made to get flowing wells at the town of Pontotoc, but without success. It should be remembered that this town is located on the crest of Pontotoc Ridge, the northern extension of which is the source of the flowing wells in the vicinity of Ecru. Pontotoc is more than 100 feet higher than Ecru, where the water rises only to the surface. It is very improbable, therefore, that flowing water could be obtained at Pontotoc. Considering the dip of the underlying Cretaceous to be constant, good pumping water from the Tuscaloosa-Eutaw horizon may be expected at a depth of 893 feet, and it should rise to within 250 feet of the surface. The same water in the southern part of the county would be obtained at a still greater depth.

Prentiss County.—The high east-west ridge across this county makes it impossible to get flowing wells anywhere within it. Good pumping water could be obtained from the Tuscaloosa sands, at a maximum depth of 500 feet, in the vicinity of Booneville. The water would rise to within about 260 feet of the surface, and perhaps less, depending on the elevation of the catchment area to the east.

Quitman County.—The Wilcox sands, which furnish the flowing wells at Batesville, continue their westward dip of about 16 feet to the mile, and in Quitman County the wells range in depth from 636 to 860 feet. One well furnishes 100 gallons per minute from a 2½-inch pipe. One of the deep wells at Riverside (No. 278) has the following interesting log:

Log of well at Riverside.

	Feet.
9. Sand and silt	40
8. Blue mud	45
7. Water-bearing sand	50
6. Gravel sand	40
5. Soapstone alternating with sand	220
4. Rock	1
3. Soapstone and rock	50
2. Green sand to lignite which is 10 inches thick	10
1. Soapstone containing mica and white sand	180
Total depth	636

Nos. 1 to 5, inclusive, are strata in the Wilcox, while the upper 175 feet belong to the Port Hudson formation. The 370 feet represented by Nos. 3, 4, and 5 are the upper clay of the Wilcox, which is shown in the Memphis well and outcrops in the river bed at Grenada.

Rankin County.—Flowing wells are not possible in this county, except along Pearl River. Wells in the southern part of the county are supplied from the Grand Gulf formation. The water is often strongly mineral, as it comes from lignitic clays and sands. Strong springs are common in the western part of the county. Some of these spring waters are hauled to Jackson in large demijohns and sold for drinking water.

Scott County.—About half of this county is prairie land of the Jackson formation. The town of Forest is in a belt of level land or "flat woods," 5 to 10 miles wide, running from the southeast to the northwest corner of the county. When water is found in this prairie soil it is very unsatisfactory for drinking, as it contains a large amount of lime. At Forest one well is reported to be 520 feet deep. This failed during the fall of 1903 and a new one was drilled later. Here and there over the prairie are hills and ridges covered with remnants of the Lafayette, which furnish excellent water in shallow wells and springs. Good deep-well water can be obtained from the Claiborne horizon at 500 to 700 feet. In some sections of the county the water will rise very near the surface.

Sharkey County.—No wells are reported. Flowing wells are not to be obtained. Good wholesome water from the Claiborne horizon would be reached at about 1,500 feet.

Simpson County.—Water is obtained from the Grand Gulf and the Lafayette. Flowing wells could doubtless be obtained along Pearl River at a maximum depth of 500 feet.

Smith County.—The elevation is high and the water is poor in the northern part of the county. Flowing wells from the lower Grand Gulf are obtained in the southeastern part, in the vicinity of Taylorsville. The deepest (No. 281) in the county has a depth of 1,135 feet. The strata passed through are as follows (no thicknesses are given): Surface clay, sand, blue sand mixed with sand, sand rock, blue mud, and sand. Water was obtained in white sand.

Sunflower County.—Only two wells have been reported from Sunflower County. The temperature of the Moorhead well (No. 287) is 60° (?). The Claiborne horizon lies at a depth of more than 1,000 feet in the western part of the county, and the water will not generally rise above the surface. In eastern Sunflower County it is possible to get good flowing wells at about 900 to 950 feet. In boring for water a depth of 900 feet on the eastern border of the county should be counted on, with an additional 25 feet for each mile to the west.

Tallahatchie County.—This county, like Leflore County, which lies just south of it, has high hills in the adjoining county to the east. Drillers say that it is more difficult to obtain flowing wells in Tallahatchie than in Leflore County. This is perhaps due to two causes. The artesian water in Leflore comes from the Claiborne horizon, while that in Tallahatchie comes from the Wilcox. There is also a possibility that the water-bearing sands underlying Tallahatchie County may be much finer and mixed with clay, which would make the water horizon less certain.

Tate County.—No artesian wells are found in Tate County. The wells in the eastern edge of the Yazoo Delta in this county along Coldwater River have the following general section: Surface clay 15 to 20 feet, gravel 12 to 15 feet, red sand merging into white sand, below which come pipe clay and water-bearing sand. East of the delta good shallow wells and springs are found at the base of the Lafayette.

Tippah County.—The eastern part of Tippah County has a north-south line of high hills in which the Ripley formation outcrops. This formation furnishes fine water, which has not been found to rise above the surface. There is a possibility of getting flowing wells on Tippah Creek, in the western part of the county.

The outcrop of the Midway limestone is marked by a line of springs, the water of which is chalybeate. It obtains its iron in passing through the sandy marl lying above the limestone.

Tishomingo County.—This county contains numerous springs along the contact of the older Devonian and Carboniferous rocks with the lower Cretaceous. The Iuka Springs are noted for their curative properties.

Tunica County.—Flowing wells can be obtained in the eastern half of Tunica County at a maximum depth of 875 feet. The water will probably not rise above the surface along the western border, but will reach within an easy pumping distance.

Union County.—Central Union and north-central Pontotoc counties contain a small area of artesian wells. The source of the water is the lower Ripley sands on the west slope of Pontotoc Ridge, in the eastern part of these counties. The catchment area of the Ripley is comparatively limited, and the head of the water has been considerably lowered by increasing the number of wells. The first wells at New Albany had a very high pressure, but most of them now have to be pumped. Water is generally reached at a depth of less than 250 feet.

Warren County.—Only one deep well is reported from Warren County. This is the Vicksburg well, which is 1,060 feet deep, and in which, when it was completed, the water rose to the surface. Wells south of Vicksburg obtain their supply from the Grand Gulf and the Lafayette; those north of the town from the Lafayette only.

Washington County.—No flowing wells are reported from Washington County. The western part is too far removed from the sources of the water to obtain flowing wells, but artesian wells should be obtained in the eastern part at a maximum depth of 1,200 feet and perhaps less. Flowing wells are obtained at Tchula, in central Holmes County

at a depth of about 770 feet. If we assume a westward dip of 25 feet per mile, the same water can be reached at Belzona at about 1,150 feet.

The following log was given of the deep well (No. 307) at Leland. This well is 512 feet in depth and rises to within 14 feet of the surface.

Log of deep well at Leland.

	Feet.
Buckshot clay	2
Fine sand	138
Hard gravel	14
Hard blue clay	298
Coarse gray sand	60
	512

Water was obtained in the last 60 feet of sand. In the 298 feet of hard clay there were six different strata of rock from 6 inches to 2 feet thick. The driller reports that these rock strata are persistent over this region of the Yazoo Delta. In some wells ten or twelve different strata are found, and in others not more than three or four. The maximum thickness of these rocks is 4 feet. The driller further says that the hard gravel is very persistent, is always found at about the same depth, and is never less than 10 nor more than 14 feet thick. The water carries 9 grains of solid matter to the gallon, 7 grains being soda.

Wayne County.—There are numerous flowing wells along Chickasawhay River in Wayne County. The water comes from the Claiborne horizon and is usually red and of an alkaline character.

Well No. 309, at Waynesboro, yields red water, which contains 72 grains of sodium carbonate to the gallon and considerable iron. All the wells at Waynesboro start in a thin sandy layer, possibly Lafayette, which rests upon the Vicksburg, and reach the lower Lisbon beds, from which they obtain red water.

Webster County.—No deep wells are reported. Water is supplied from shallow wells.

Wilkinson County.—No deep wells are reported. Water is supplied from shallow open wells.

Winston County.—Plenty of water is obtained from the Wilcox, but at many localities it is very bad, owing to the great amount of lignitic clay.

Yalobusha County.—There are two artesian areas in Yalobusha County, one in the vicinity of Coffeeville and the other at Water Valley, but there are, no doubt, other undeveloped areas along the lower streams. The source of the artesian water at the above-mentioned places is the lower division of the Wilcox.

There are eight flowing wells in the town of Coffeeville and three others near the city limits. They range in depth from 160 to 400 feet. The log of well No. 315 showed 40 feet of surface sand; 100 feet of greensand; then gravel, lignite, and sand to water, which was obtained at 238 feet. Where the water-bearing sand was encountered, the drill dropped 8 or 9 feet into it. This is a white sulphur water and is said to be wholesome.

Wells are easily obtained in Shooner River Valley, and the drillers guarantee a flowing well at a cost of $100.

Yazoo County.—One of the deepest wells (No. 319) in the State was recently drilled at Yazoo. It failed to get flowing water at a depth of 1,567 feet, though there are flowing wells in the town of less than half that depth. The temperature of one of the flowing wells southwest of town is reported to be 70° F.

DEEP-WELL RECORDS

Partial list of deep wells

[Reported to the United

No.	County.	Town.	Owner.	Location. Township.	Location. Range.	Location. Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
*1	Adams	Natchez	Waterworks Co	....	....	....	1901	6	340	.....	− 30
*2	.....do	.....do	Oil mills	....	....	....	.....	6	170	.....	− 20
3	.....do	.....do	Gas Company	....	....	....	.....	6	165	.....	− 10
*4	.....do	.....do	Electric Light, Heat and Power Co.	....	....	....	.....	6	430	.....	−160
5	.....do	.....do	C. S. Bennett	....	....	....	1899	10	115	115	− 85
6	.....do	.....do	Cotton mills No. 2	....	....	....	1902	8	175	.....	− 8
7	.....do	.....do	Natchez ice factory	....	....	....	1902	6	517	500	− 8
8	.....do	.....do	.....do	....	....	....	1902	6	300	264	− 36
*9	.....do	Pine Ridge	W. P. Henderson	....	....	....	1896	6	97	85	− 85
*10	Alcorn	Corinth	E. S. Candler	2	2	7	1900	6	100	100	− 20
*11	.....do	.....do	Waterworks Co	....	....	....	1903	12	345	.....	− 20
*12	Attala	Kosciusko	A. M. Hanna	14	7	21	1899	4½	276	200	− 76
13	Bolivar	Cleveland	Sillers & Owens	22	5	21	1901	3	1,000	1,000	+ 0
14	.....do	.....do	C. S. Glassco	22	5	21	1901	4	1,000	1,000	+ 0
15	.....do	O'Reilly	O'Reilly	21	5	23	1901	4	1,002	.....	+ 0
16	Carroll	Carrollton	A. H. George	19	4	6	1898	8	85	70	− 70
*17	.....do	.....do	City	....	....	....	1900	4	1,250	300 450	−
*18	.....do	.....do	Waterworks Co	19	3	....	1900	4	400	400	+ 0
19	.....do	Vaiden	S. E Turner	17	5	....	1901	2	105	105	+ 12
*20	Chickasaw	Okolona	City	....	....	....	1899	6	550	550	− 80
*20a	.....do	.....do	Mobile and Ohio Railroad.	....	....	....	.....	....	548	473	− 22
21	Choctaw	Chester	J. T McCafferty	18	10	15	1892	10	86	80	− 60
*21a	Claiborne	Hermanville	W G. Herrington	11	4	3	1878	12	86	75	− 75
*22	Clarke	Barnett	A. Krouse	2	14	20	1899	4	350	125	−
*23	.....do	.....do	Smith's Mill Co	2	14	31	1902	6	600	.....	−
*24	.....do	De Soto	Town	2	15	36	1898	3	190	150	+ 3
*25	.....do	Enterprise	.....do	4	14	24	1895	2	156	150	+ 20
*26	.....do	.....do	R. M. Buckley	4	15	19	1896	3	198	.....	− 2
27	.....do	.....do	John Kemper	4	14	26	1901	3	150	150	+ 15
28	.....do	.....do	Bonny	4	14	23	1901	3	200	.....	+ 10
*29	.....do	.....do	S. J. Taylor	4	14	23	1900	3	210	210	− 3
30	.....do	.....do	Mrs. O'Ferral	4	15	19	1900	3	400	210	− 20
*31	.....do	Quitman	J. B. Evans	2	15	1	1898	3	232	232	+ 15
32	.....do	.....do	Mississippi Lumber Co.	2	15	2	1899	3	179	179	+ 20

*See text, pp. 27-29, for additional data.

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eological Survey.]

ob-at te.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
	Hard		None apparent.	None apparent.	Lafayette	Grand Gulf	*1
	do		Neither	do	Loess	Base of Lafayette	*2
			do		do	Lafayette	3
			None apparent.		do	Grand Gulf	*4
	Good		Neither		do	Lafayette	5
	Hard		do	Little	do	Grand Gulf	6
	do	50	None apparent.	None apparent.	Lafayette	do	7
sed	Good	70	do	do	do	do	8
	Hard			Easily lowered.	Loess	Lafayette	*9
	do		None apparent.	None apparent.	Lafayette	Eutaw	*10
	do	20	do	do	do	Tuscaloosa	*11
	do	100	do	Little	Claiborne	Wilcox	*12
	Soft	75	None		Port Hudson.	do	13
	do	100	None apparent.	None apparent.	Alluvial bottom.	Claiborne	14
	do	100	None		Port Hudson.	Wilcox	15
	do		None apparent.				16
		0			Lafayette?	Claiborne	*17
	Soft	62	None apparent.		Alluvial bottom.	do	*18
	do		Neither				19
sed	do	138	None apparent.	None apparent.	Cretaceous	Eutaw	*20
					Lafayette	do	*20a
	Hard	½	do	Easily lowered.	do	Wilcox	21
				None	do	Grand Gulf	*21a
					Jackson	Claiborne	*22
					do	do	*23
	Soft, alkaline.	½	Decreased		Claiborne	do	*24
	Soft	15	Slight		Alluvial soil	Wilcox	*25
	do		Decreased	Lowers easily.	Lafayette	do	*26
	do		Little		Alluvium	do	27
	do		do		Lafayette	do	28
	do		Decreased slightly.	Slight	do	do	*29
	do		Decreased	Easily lowered.	do	do	30
	do	3	Variable	do	do	do	*31
	do	3		do	do	do	32

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Range.	Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
*33	Clarke	Quitman	Town	2	15	1	1898	3	175	175	+ 15
*34	do	Shubuta	do				1898	2	400		+ 15
*35	do	do	Weems				1901	2	422	400	+ 20
36	do	do	W. P. Cooper				1902	6	420	375	+ 30
37	do	do	W. H. Paterson				1900	2	400	400	+ 20
38	do	do	F. H. Floyd				1901	2	400	400	+ 20
39	do	do	D. C. Ward				1902	2	170		+ 10
40	do	do	W. P. Cooper				1900	2	165		+ 0
41	do	do	Moseley				1901	2	175	160	+ 10
42	do	do	Patterson				1901	2	160		+ 10
*43	do	do	Cooper's mill				1897	2	145		− 20
44	do	do	Stovall				1900	2	165		+ 15
*45	do	do	A. Johnston	1	16	25	1896	2	280	260	+ 20
46	do	do	Eggerton				1900	2	175		+ 10
47	do	do	Floyd Hotel				1899	2	165		+ 10
48	do	do	Poole & Brown				1900	2	175		+ 10
49	do	do	Brown's mill				1901	2	165		+ 10
50	do	do	Leggett				1902	2	170		+ 10
51	do	Stonewall	T. L. Wainwright	3	15E	5	1897	2½	300	250	+ 20
*52	Clay	West Point	City				1895	3	600	600	+ 1
*52a	do	Cedar Bluffs	do						650	650	− 100
53	Coahoma	Eagles Nest	James L. Alcorn's estate.	28	3	22	1898	1½	825	825	+ 0
*53a	do	Clarksdale	Town				1897	2½	876	876	+ 10
54	do	Jonestown	Geo. Richberger	28	6		1902	2	800	700	+ 0
*55	do	Lyon	Lamar Fontaine	27N	3 W	18	1901	4	975	970	+ 35
*56	Copiah	Wesson	Dr. E. A. Rowan	9	8E	34	1890	36	120	120	− 100
*56a	Grenada	Grenada	City						620	490	+ 0
*57	Hancock	Bay St. Louis	College				1888	3	738		+ 42
*58	do	do	do				1892	3	750		+ 42
*59	do	do	R. E. Craig				1901	3	529		+ 17
*60	do	do	G. W. Dunbar Sons' Co.				1888	2	250		+ 20
*61	do	do	do				1898	3	338		+ 35
*62	do	do	Dr. F. Loeber				1890	3	669	656	+ 40
*63	do	do	McClyde Turpentine Co.				1903	3	328		+ 25

* See text, pp. 28-30, for additional data.

N MISSISSIPPI—Continued.

the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Soft	3	Variable		Lafayette	Wilcox	*33
do	do	20	Decreased		Jackson	Claiborne	*34
do	do		None apparent.		Jackson	Claiborne	*35
do	do	40	do		do	do	36
do		40	do		do	do	37
do	Soft	40	do		do	do	38
do	do	15	do		do	do	39
do	do	15	Decreased slightly.		do	do	40
do	do	15	None apparent.		do	do	41
do	do	15	do		do	do	42
	do	20	do		do	do	*43
Flows	do	10	do		do	do	44
do	do	15	Decreased		do	do	*45
do	do	10	None apparent.		do	do	46
do	do	10	Slight decrease.		do	do	47
do	do	10	None apparent.		do	do	48
do	do	10	do		do	do	49
do	do	15	do		do	do	50
do	do	25	Decreased 25 per cent.		Lafayette	Wilcox	51
do	Best		None apparent.		do	Tuscaloosa	*52
					Selma	do	52a
Flows	Soft	8	None apparent.		Alluvium?	Wilcox	53
do	do	3	do		do		*53a
do	do	8	do		River bottoms.	Wilcox	54
do	do	22	do		Port Hudson	do	*55
Pump	Hard		Neither	Slight	Lafayette	Grand Gulf	*56
Flows					do	Wilcox	*56a
do	Soft	8	Decreased		Post-Tertiary.		*57
do	do	5	do		do		*58
do	do	100	None apparent.		do	Post-Tertiary	*59
do	do	35	do		do	do	*60
do	do	100	do		do	do	*61
do	do	40			do		*62
do	do	20	None apparent.		do	Post-Tertiary	*63

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Location. Range.	Location. Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
*64	Hancock	Bay St. Louis.	Chas. Sanger				1892	3	385	385	+ 15
*65	do	do	do				1889	3	384	361	+ 30
*66	do	do	St. Stanislaus College.				1888	2	420	190 420	+ 20
*67	do	do	St. Joseph's Academy.				1888	2	418	418	+ 20
68	do	do	R. Thelhiard				1893	2½	345	315	+ 13
*69	do	do	Tally Lumber Co.				1903	4½	150		+ 23
70	do	Logtown	Bush & Johnson				1899	2½	620		+ 25
*71	do	Nicholson	D. Carver	6	17	34	1896	2	250	225	+ 0
72	do	Picayune	J. W. Simmons	6	17	15	1895	2	500	500	+ 25
*73	do	Waveland	P. Helwig				1891	2½	356		+ 15
*74	do	do	Mr. Bookta					3	366	320	+ 0
*75	do	do	A. Matranger				1894	3	438	419	+ 15
*76	do	do	F. Caseneuve					3	376	357	+ 15
77	do	do	M. A. Dauphin				1889	2½	483	467	+ 23
*78	do	do	T. R. Fell				1888	2½	461	410	+ 20
79	do	do	Paul Conrad				1889	3	432	412	+ 16
80	Harrison	Biloxi	Barataria Canning Co.				1886	3	620		+ 75
81	do	do	Biloxi Canning Co				1902	3	715		+ 65
82	do	do	Biloxi Cemetery				1896	2½	580		+ 35
83	do	do	Biloxi Ice Co				1894	3½	920		+ 75
84	do	do	Jno. Caraway				1896	2½	560		+ 30
85	do	do	Mrs. Carter				1896	2½	600		+ 30
86	do	do	City				1889	2½	420		+ 25
87	do	do	do				1889	2	414		+ 20
88	do	do	do				1889	4½	860		+ 80
89	do	do	F. H. Dunbar				1891	2	420		+ 20
90	do	do	Thos. Gill				1895	3	720		+ 70
91	do	do	H. Howard				1885	2	420		+ 25
92	do	do	F. T. Howard				1885	2½	415	400	+ 30
93	do	do	do				1886	4½	920		+ 80
94	do	do	do				1886	2½	420	410	+ 30
95	do	do	Ice factory					3½	890		+ 80
96	do	do	E. C. Joullian				1901	2½	650		+ 60
97	do	do	L. Lopez				1886	2	600		+ 27
98	do	do	do				1886	2½	620		+ 60
99	do	do	do				1897	3	700		+ 7
100	do	do	J. H. Keller				1886	2½	420		+ 3
101	do	do	Waterworks Co					4½	860		+ 5
101a	do	Bond	J. E. North						690	530	−16

* See text, pp. 30-31, for additional data.

SISSIPPI—Continued.

ite of Mississippi—Continued.

b- at e.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
....	Soft....	5	Fluctuates....	.....	Post-Tertiary.	.....	*64
....	....do...	30	None apparent.	.....	....do.....	.....	*65
....	....do...	40	....do.....	.....	....do.....	Post-Tertiary...	*66
....	....do...	40	....do.....	.....	....do.....	....do.....	*67
....	....do...	45	....do.....	.....	....do.....	.....	68
....	....do...	100	....do.....	.....	....do.....	Post-Tertiary....	*69
....	....do...	60	....do.....	.....	....do.....	Grand Gulf.....	70
....	....do...	28	Neither.....	.....	Port Hudson	Grand Gulf.....	*71
....	....do...	27	....do.....	.....	Post-Tertiary.	.....	72
....	....do...	25	None apparent.	.....	....do.....	.....	*73
....	....do...	75	....do.....	.....	....do.....	.....	*74
....	....do...	30	....do.....	.....	....do.....	.....	*75
....	....do...	30	....do.....	.....	....do.....	.....	*76
....	....do...	25	....do.....	.....	....do.....	.....	77
....	....do...	30	....do.....	.....	....do.....	.....	*78
....	....do...	30	....do.....	.....	....do.....	.....	79
....	....do...	150	....do.....	.....	....do.....	.....	80
....	....do...	125	....do.....	.....	....do.....	.....	81
....	....do...	70	....do.....	.....	....do.....	.....	82
....	....do...	300	....do.....	.....	....do.....	.....	83
....	....do...	70	....do.....	.....	....do.....	.....	84
....	....do...	60	....do.....	.....	....do.....	.....	85
....	....do...	50	....do.....	.....	....do.....	.....	86
....	....do...	35	....do.....	.....	....do.....	.....	87
....	....do...	425	....do.....	.....	....do.....	.....	88
....	....do...	40	....do.....	.....	....do.....	.....	89
....	....do...	150	....do.....	.....	....do.....	.....	90
....	....do...	50	....do.....	.....	....do.....	.....	91
....	....do...	40	....do.....	.....	....do.....	.....	92
....	....do...	175	....do.....	.....	....do.....	.....	93
....	....do...	50	No change....	.....	....do.....	.....	94
....	....do...	300	None apparent.	.....	....do.....	.....	95
....	....do...	100	....do.....	.....	....do.....	.....	96
....	....do...	50	....do.....	.....	....do.....	.....	97
....	....do...	100	....do.....	.....	....do.....	.....	98
....	....do...	175	....do.....	.....	....do.....	.....	99
....	....do...	60	....do.....	.....	....do.....	.....	100
....	....do...	450	....do.....	.....	....do.....	.....	101
....	....do...	.....	....do.....	.....	....do.....	Grand Gulf.....	101a

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Location. Range.	Location. Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
*102	Harrison	Deliste	W. S. Keel	8	13	2	1898	2	380	.....	+25
103	do	Gulfport	U. S. Marine Hospital, Ship Island.	....	....	....	1900	3	760	.....	+50
104	do	do	Ice factory	....	....	....	1891	2½	540	.....	+25
105	do	do	Chautauqua Circle	....	....	....	1891	3	680	.....	+30
106	do	do	G. & S. I. R. R.	....	....	....	1896	2½	680	.....	+25
107	do	do	do	....	....	....	1899	3	920	.....	+75
108	do	do	do	....	....	....	1903	4½	960	.....	+80
109	do	Handsboro	—— Zimmerman	....	....	....	1896	2½	500	.....	+15
110	do	do	H. Leinhard	....	....	....	1896	2½	700	.....	+30
111	do	do	Leonard Lumber Co.	7	11	25	1895	3	700	.....	.....
*112	do	Howison	Howison Lumber Co.	....	....	....	1897	2	1,480	1,400	−35
113	do	Longbeach	F. Jabenski	....	....	....	1896	2½	580	.....	+25
114	do	do	—— McCaughn	....	....	....	1897	2½	600	.....	+35
114a	do	Lyman	City	....	....	....	.....	....	480	375	.....
115	do	Mississippi City.	F. W. Elmer	....	....	....	1896	4½	860	850	0
116	do	do	L. & N. R. R.	....	....	....	1885	2	520	.....	+30
117	do	do	Mr. Clemaceau	....	....	....	1897	3	740	.....	+80
118	do	do	C. P. Ellis	....	....	....	1896	3	720	.....	+75
119	do	do	Mr. De Buys	....	....	....	1895	2½	640	.....	+30
120	do	do	Mr. Soria	....	....	....	1885	2	514	.....	+30
121	do	Nugent	.....	....	....	....	1902	2½	300	300	−30
*122	do	Pass Christian.	R. M. Walmsley	....	....	....	1902	3	720	.....	+50
*123	do	do	Wm. Hardin	....	....	....	1892	3	620	.....	+40
*124	do	do	C. L. Chaptal	....	....	....	1892	2½	543		+25
*125	do	do	A. Swanson	....	....	....	1892	2½	560	.....	+30
*126	do	do	E. Saunders	....	....	....	1884	2	575	.....	+25
*127	do	do	City	....	....	....	1885	2	420	.....	+30
*128	do	do	do	....	....	....	1887	2½	520	.....	+35
*129	do	do	do	....	....	....	1893	2	620	.....	+30
*130	do	do	do	....	....	....	1890	3	640	.....	+50
*131	do	do	do	....	....	....	1890	3	625	.....	+60
*132	do	do	do	....	....	....	1890	3	840	.....	+90
*133	do	do	G. H. Taylor	....	....	....	1898	2	420	.....	+25
*134	do	do	do	....	....	....	1898	3	725	.....	+80
*135	do	do	E. Connery, jr	....	....	....	1886	2	520	510	+35
*136	do	do	L. C. Tallon	....	....	....	1901	3	640	.....	+40
*137	do	do	A. Mullinburger	....	....	....	1888	2½	514	.....	+40

*See text, p. 31, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Contiuued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Soft	25	None apparent.		Post-Tertiary.	Lafayette	*102
do	do		do		do	Grand Gulf	103
do	do	60	do		do		104
do	do	80	do		do		105
do	do	60	do		do		106
do	do	150	do		do		107
do	do	175	do		do		108
do	do	60	do		do		109
do	do	100	do		do		110
do	do	175	Variable		Alluvium	Pascagoula	111
		0					*112
Flows	Soft	60	None apparent.		Post Tertiary.		113
do	do	70	do		do		114
					do	Grand Gulf	114a
Flows	Soft	450	None		do	do	115
do	do	50	None apparent.		do		116
do	do	160	do		do		117
do	do	150	do		do		118
do	do	70	do		do		119
do	do	50	do		do		120
do	do	60	do				121
do	do	150	do		Post Tertiary.		*122
do	do	170	Little		do		*123
do	do	60	do		do		*124
do	do	70	do		do		*125
do	do	60	do		do		*126
do	do	40	do		do		*127
do	do	50	do		do		*128
do	do	40	None apparent.		do		*129
do	do	150	do		do		*130
do	do	150	do		do		*131
do	do	225	do		do		*132
do	do	25	do		do		*133
do	do	200	do		do		*134
do	do	60	None		do	Grand Gulf ?	*135
do	do	80	None apparent.		do		*136
do	do	50	do		do		*137

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Location. Range.	Location. Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) top of well.
								In.	*Feet.*	*Feet.*	*Feet.*
*138	Harrison	Pass Christian.	W. R. Wilson				1898	2½	510		+ 25
*139	do	do	Mrs. Watt				1896	3	670		+ 75
*140	do	do	E. Connery, sr.				1887	2½	510		+ 50
*141	do	do	Jno. Curran				1894	3	620		+ 40
*142	do	do	Jno. A. Sutter				1894	2½	514		+ 45
*143	do	do	S. F. Heaslip				1895	2½	620		+ 40
*144	do	do	E. Hocaday				1895	2	520		+ 30
*145	do	do	Mexican Gulf Hotel				1888	2½	520		+ 30
*146	do	do	J. H. Menge				1890	2½	600		+ 30
*147	do	do	H. Buddig				1889	2½	600		+ 25
*148	do	do	J. M. Ayer				1891	2	540		+ 25
*149	do	do	do				1891	2	540		+ 25
*150	do	do	Pass Packing Co				1899	3	920		+ 80
*151	do	do	Doctor Perault				1903	3	1,020		80
*152	do	do	Magnolia Hotel				1902	3	900		+ 90
*153	do	do	H. Payne				1890	2½	614		+ 30
153a	do	Ship Island	Gov. light-house					2	750	700	+
154	do	Saucier	Biloxi Lumber and Export Co.				1897	3	720		
155	do	Wortham	J. C. Wilmoth	6	12	1	1902	4	836	786	+ 15
156	Hinds	Jackson	Ice factory				1896	6	604		− 58
157	do	do	Baptist Orphanage				1900	6–4½	200	180	−120
*157a	do	Bolton	City				1903	6	1,517	1,020	− 80
158	Holmes	Durant	I. C. R. R					5	375		+ 0
158a	do	do	City				1905	6	500	500	+ 1
158b	do	Cruger	Ed. Archer	17	1	26	1897	2	800	700 and 800	+
158c	do	Lexington	G. A. Wilson					2	800		+
*159	do	Pickens	W. S. Gordon?	12	3	15	1901	4–2	265	265	+ 2
*160	do	Tchula	City				1900	4–2	1,125		+ 85
161	do	do	W. B. Jones	16	1	5	1902	3–2	770	770	
*162	do	West	Dr. L. S. Rogers	15	5	3	1901	3	160	130	+ 15
*163	Jackson	Fontainebleau	J. B. Carson				1893	2½	720	700	+ 30
*164	do	do	A. E. Lewis				1889	2½	625	600	+ 40
165	do	Moss Point	Dantzler Lumber Co.				1889	2½	560		+ 25
*166	do	do	Denny Lumber Co				1902	3	900		+ 30
*167	do	do	F. H. Lewis				1902	6–4	1,550	650	+ 30

* See text, pp. 31–33, for additional data.

IN MISSISSIPPI—Continued.

in *the State of Mississippi*—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum	No.
		Gals.					
Flows	Soft	60	None apparent.		Post Tertiary.		*138
do	do	170	Little		do		*139
do	do	50	None apparent.		do		*140
do	do	100	do		do		*141
do	do	60	do		do		*142
do	do	70	do		do		*143
do	do	50	do		do		*144
do	do	60	do		do		*145
do	do	60	do		do		*146
do	do	50	do		do		*147
do	do	50	do		do		*148
do	do	50	do		do	Post-Tertiary	*149
do	do	250	do		do		*150
	do	250	do		do		*151
Flows	do	250	do		do	Pascagoula marl.	*152
do	do	60	do		do		*153
Flows		50			Recent	Pascagoula	153a
		0					154
do	Soft	75	Decreased	Lowered slowly.	Lafayette?	Pascagoula	155
Steam pump	Good	35	Little	Slight	do	Upper Claiborne.	156
do	Hard	30	do	do	do	Under Jackson marl.	157
do	Soft		None	None	Grand Gulf.	Wilcox	*157a
Flows	do		None apparent.		Second river bottoms.	do	158
do	do				Lafayette	Claiborne	158a
do		90		None	Port Hudson.	do	158b
do					do	do	158c
do	Hard	12	None apparent.		Second river bottoms.	do?	*159
do	Soft	130	do				*160
do	do	200	None				161
do	do	20	None apparent.		Lafayette sand.	Wilcox	*162
do	do	70	do		Post Tertiary.	Pascagoula	*163
do	do	60	do		do	do	*164
do	do	40	do		do	do	165
Flows	Soft	25	do		do		*166
do	Hard	400	Neither			Grand Gulf?	*167

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location.			Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
				Township.	Range.	Section.					
								In.	*Feet.*	*Feet.*	*Feet.*
*168	Jackson	Ocean Springs	J. J. Kuhn	....	....	....	1891	2½	880	.....	+80
169	do	do	A. A. McGinnes	....	....	....	1885	2½	620	.....	+40
170	do	do	N. B. Smith	....	....	....	1885	2½	514	.....	+20
*171	do	do	Wm. De Pass	....	....	....	1898	2½	520	.....	+30
172	do	do	Chas. Zeigler	....	....	....	1901	2½	560	.....	+30
173	do	do	Mr. Sullivan	....	....	....	1901	2½	540	.....	+25
174	do	do	J. Feitag	....	....	....	1888	2½	525	.....	+30
175	do	do	John Blank	....	....	....	1902	2½	550	.....	+50
176	do	do	Captain Benson	....	....	....	1890	2½	550	.....	+50
*177	do	do	People's waterworks.	....	....	....	1901	3	965	.....	+75
*178	do	do	George Rose	....	....	....	1897	4	900	.....	+16
*179	do	do	George Rose, of New York.	....	....	....	1903	8–4	1,200	900	0
*180	do	do	Electric Ice Co	....	....	....	1903	3	866	.....	0
*181	do	Scranton	City	....	....	....	1897	6	800	.....	+43
*182	do	do	F. H. Lewis	....	....	....	1891	2½	720	.....	+30
*183	Jones	Ellisville	County	7	12	5	1902	6	1,300	350	−30
*184	do	Laurel	Kingston Lumber Co.	....	....	....	1902	6	365	325	−40
185	do	do	Cotton mills	9	11	32	1902	6	210	200	−40
*186	do	do	Waterworks	9	11	32	1901	8	370	370	−40
187	do	do	Eastman, Gardner & Co.	9	11	32	1900	6	215	200	−40
187a	Kemper	Forrest	City	....	....	....	....	....	219	217	−90
188	Lafayette	Oxford	do	8	3	28	1896	10	185	100	−50
189	do	do	University	8	3	28	1897	....	185	100	−50
189a	Lamar	Lumberton	Hinton Lumber Co	....	....	....	....	8	1,800	.....	.....
*190	Lauderdale	Lauderdale	M. & O. R. R	8	17	24	1902	6	133	.....	− 6½
190a	do	Meridian	City	....	....	....	....	....	900	.....	−30
191	do	Lauderdale	John Nunnery	8	17	24	1902	2½	108	.....	+ 1½
*192	do	do	M. Smith	8	17	24	1901	2	216	.....	− 7
193	do	do	John Nunnery	8	17	24	1901	2½	108	.....	+ 1½
*194	do	do	M. & O. R. R	8	17	24	1901	6	132	.....	− 6½
195	do	Meehan Junction.	Meehan-Rounds Lumber Co.	6	14	33	1902	3	324	.....	0
*196	do	do	do	6	14	33	1902	3	324	.....	+ 0
*197	do	Meridian	City	....	....	....	1902	5	305	.....	− 5½

*See text, pp. 32–33, for additional data.

N MISSISSIPPI—Continued.

the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Soft	150	None apparent.		Post Tertiary.	Pascagoula	*168
do	do	80	do		do	Clay above Pascagoula.	169
do	do	25	do		do	Post-Tertiary clays.	170
do	do	60	do		do	do	*171
do	do	60	do		do	do	172
do	do	50	do		do	do	173
do	do	60	do		do	do	174
do	do	26	do		do	Post-Tertiary sands.	175
do	do	100	do		do	do	176
do	do	250	Neither		do	Pascagoula	*177
do	do	100	None apparent.		do	do	*178
do	Alkaline		do		do	do	*179
do	Soft	240	do		do		*180
do	do	150	do		do	Pascagoula	*181
do	do	60	do		do	do	*182
	Hard				Lafayette	Grand Gulf?	*183
ump	Soft	150	None apparent.	None apparent.	do	do	*184
do	do	150	do	do	do	do	185
pressed air.	do	280	do	None	do	do	*186
do	do	140	do	do	do	do	187
					do	Claiborne	187a
mp	Soft		None apparent.	Slight	do	Wilcox	188
do	do		do	None observed.	do	do	189
					do	Grand Gulf	189a
mp	Soft	115	None apparent.	Lowered	do	Wilcox	*190
					do	do	190a
ws	Soft		None apparent.		do	do	191
mp	do		do		do	do	*192
ows	Hard		do		Wilcox	do	193
mp	do	100	do	Slight	do	do	*194
ows	Soft	11	Neither		Lafayette	do	195
do	do	11	do		River alluvium.	do	*196
Pumps	Hard				Creek bottom.	do	*197

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location. Township.	Range.	Section.	Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
								In.	*Feet.*	*Feet.*	*Feet.*
198	Lauderdale	Meridian	City				1902	2½	257		+4
*199	do	do	do				1882	2	905		−20
200	do	do	do				1903	5	305		−5½
*201	do	do	Ice factory				1890	3	680		−25
*202	do	Siding	W. J. Graham	6	14	22	1895	3	77	40	+22
*203	do	do	Mrs. Martha Maxwell.	6	14	22	1896	3	75		+0
204	Lawrence	Silver Creek	A. T. Longino	7	20	10		12	80	70	−70
205	do	do	Dr. B. B. Cowant	7	20	6	1898	10	89	73	−73
*205a	Lee	Baldwyn	Brick Co.						380		−5
206	do	Guntown	Robt. Gambrell	7	6	12	1870	5	70	70	−40
206a	do	do	City						300		−30
207	do	Nettleton	Jno. McGaughey	11	6	11	1898	4	140	110	+0
208	do	Plantersville	R. S. Rodgers	10	6	34	1899	6	160	149	+0
209	do	do	Robt. Birmingham	11	6	1	1898	4½	140	140	−60
*210	do	Rusk	L. B. Gandy	10	6	3½	1902	3½	322	300	+0
211	do	do	W. S. Brown	11	6	2	1886	36	130	80	+4
212	do	Shannon	J. K. Whitesides	11	6	19	1903	4½	300		−15
212a	do	Tupelo	U. S. Bureau of Fisheries.				1903	4½	398	320	+0
*212b	do	do	Mo. and Ohio R. R.						436	406	+0
212c	do	do	City						300	300	−8
213	do	Verona	L. T. Taylor	10	6	20	1870	10	285	200	+0
214	do	do	do	10	6	19	1889	6	400	285	−60
215	Leflore	Greenwood	A. F. Gardner	19	1	10	1901	4	490	400	+40
215a	do	do	T. B. Minyard					2	266	194	+
216	do	do	T. J. Phillips	19	1	15	1900	4	650	600	+40
*217	do	do	Ice factory				1896	4	650	600	+0
218	do	Ittabena	L. J. Young & Co.	19	1	20	1897		597		+35
219	do	do	Mahoney Bros.	19	1	20	1897	3	596½		+0
220	do	do	R. W. Baird	19	1	13	1896	3	365	348	+0
221	do	do	A. Henderson	19	1		1898	2	450		+0
*221a	do	Minter City	C. E. Feigler	22	1	15	1900	2	437	420	+40
222	Lincoln	Brookhaven	W. R. Norton	8	6	25	1901	12	60	60	−54
223	do	do	S. P. Oliver	7	8	7	1898	6	155	115	−40

*See text, pp. 33–34, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
Flows	Hard		None apparent.		Wilcox	Wilcox	198
Motor	do		do	Easily lowered.	do	do	*199
Pump	do				Second river bottoms.	do	200
Steam pump	do		None apparent.	Easily lowered.	Wilcox	do	*201
Flows	Soft		do		Buhrstone	do	*202
do	do		do		do	do	*203
	do		do	Little	Lafayette	Lafayette	204
Bucket	Hard		do	Slight	do	Grand Gulf	205
					Selma	Eutaw	*205a
Bucket	Soft		None apparent.	Slight	Lafayette clay.	Top of Tuscaloosa	206
	Hard				do	Eutaw	206a
Flows	Hard, good.	5	Neither		Selma	Tuscaloosa	207
do	Soft		None apparent.		do	do	208
Pump	Hard		do	Little	do	do	209
Flows	Soft	15	Neither		River bottom.	do	*210
do	do	3	do		Creek bottom.	do	211
Pump	do		None	None	Selma	do	212
Flows	do		do	do	do	do	212a
do	Small		Decreased		Lafayette	Eutaw	*212b
Pump					do	do	212c
Flows	Soft and pure.	10	None apparent.		Selma	Tuscaloosa	213
Pumps	Soft		do	Slight	do	do	214
Flows	do		do		Port Hudson.	Claiborne	215
do		200			do	do	215a
do	Soft	250	Decreased		do	do	216
do	do	275	None apparent.		do	do	*217
do	Soft and good.		do		Alluvium ?	do	218
do	Soft	60	do		do	Lower Claiborne.	219
do	do	100	Decreased 25 per cent.		Port Hudson.	Wilcox	220
do	do	150	Neither		do	do	221
do	do	50	do		do	Claiborne	*221a
Bucket	do		None apparent.	Easily lowered	Lafayette	Base of Lafayette	222
Air lift	do	275	do	None apparent.	do	Grand Gulf	223

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location.			Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
				Township.	Range.	Section.					
								In.	*Feet.*	*Feet.*	*Ft.*
224	Lincoln	Brookhaven	S. P. Oliver	7	8	7	1898	8	165	.....	.....
225	Lowndes	Columbus	City	....	....	....	1898	4	682	.....	+ 6
*225a	do	do	Mobile and Ohio R. R.	....	....	....	.....	....	420	.....	+ 0
*225b	do	Artesia	do	....	....	....	.....	....	597	597	− 18
*226	Madison	Canton	City	....	....	....	1896	4	1,020	.....	+ 19
227	do	do	W. H. Powell	....	....	....	1896	6	850	810	+ 16
228	do	Flora	Flora	....	....	....	1896	6	450	.....	− 40
229	Marion	Columbia	City	3	18	5	1903	3	420	400	+ 30
229a	do	do	B. W. Holloway	City.		....	1905	1½	400	400	+ 20
229b	do	do	G. H. Rankin	3	18	5	1903	2	425	425	+ 25
229c	do	do	Lamar Herrington	3	18	5	1903	1¼	425	425	+ 35
*230	Marshall	Holly Springs	City waterworks	4	2	6	1898	6	400	320	−175
231	do	Hudsonville	E. C. Mahon	2	2	27	1897	8	168	.....	−153
232	Monroe	Amory	T. R. Stevens	12	19	36	1897	2½	154	.....	+ 15
*232a	do	do	City	....	....	....	.....	2½	199	199	+ 0
232b	do	do	Railroad	....	....	....	.....	....	250	190	+ 0
*233	do	Caledonia	L. D. Booth	....	....	....	1878	6	140	.....	+ 20
233a	do	Crawford	City	....	....	....	.....	4	700	.....	−110
234	do	Gattman	K. C. and B. R. R.	13	16	32	1899	6	623	620	+ 27
234a	do	Muldon	Mobile and Ohio R. R.	....	....	....	.....	....	620	.....	− 83
*235	Montgomery	Winona	Oil and Mining Co.	19	5	25	1899	6	412	395	− 60
236	do	do	Electric Light and Ice Co.	....	....	....	1901	10-8-6	400	.....	− 75
237	Neshoba	Dixon	Chas. C. Roberts	9	10	1	1895	40	75	.....	− 70
*238	Newton	Chunkey	Wm. Harris	6	13	34	1898	2¾	160	160	+ 4
239	do	do	Jos. Sharp	5	13	13	1900	2½	150	150	+ 4
240	do	do	D. L. Ragland	5	13	35	1898	3	131	128	+ 0
241	do	Hickory	J. J. Barber	6	12	36	1898	3	150	150	+ 8
*242	do	do	W. H. Galaspy	6	12	36	1898	2½	300	300	+ 2
243	do	do	J. H. Brown	6	6	13	1897	2½	150	150	+ 10
244	Noxubee	Bigbee Valley	A. G. Cunningham	16	19	16	.....	....	500	391	+ 20
244a	do	Cooksville	W. S. Permenter	13	19	18	1898	6	500	450	− 30
*244b	do	Brookville	Mobile and Ohio R. R.	....	....	....	.....	....	657	657	− 60
*245	do	Cliftonville	J. B. Cunningham	....	....	....	.....	....	451	391	− 0
*246	do	Ravine	J. O. Poindexter	....	....	....	.....	....	725	725	− 26
247	do	do	Sebe Gavin	....	....	....	.....	....	431	431	+ 16
248	do	Macon	G. N. Ladd	....	....	....	1850	3¼	769	.....	− 0

* See text, pp. 34-36, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
.....	Soft....	275	None apparent	None apparent	Lafayette...	Grand Gulf.....	224
Flows.....	....do...	.....	.....do.....	.....	Selma.....	Tuscaloosa.....	225
.....do.....	.....	130	.....	.....	.....do.....	.....do.....	*225a
.....	.....	.....	.....	.....	.....do.....	Eutaw.....	*225b
Flows.....	Soft....	170	None apparent	None apparent	Jackson....	Wilcox.....	*226
....do.....	....do...	88	Neither.....	.....	.....do.....	Claiborne?.....	227
Pump.....	....do...	.....	.....do.....	.....	.....do.....	.....do.....	228
Flows.....	....do...	25	None apparent	.....	Second river bottoms.	Grand Gulf?.....	229
.....do.....	....do...	30	.....do.....	.....	River bottoms.	Grand Gulf.....	229a
.....do.....	....do...	60	.....do.....	.....	Bottom.....	.....do.....	229b
.....do.....	Sulphur	25	.....do.....	.....	.....do.....	.....do.....	229c
Steam pump	....do...	100	.....do.....	None apparent	Lafayette...	Wilcox.....	*230
Bucket.....	Hard...	.....	Little.....	Easily lowered.	.....do.....	.....do.....	231
Flows.....	Soft....	8	None apparent	.....	Selma.....	Tuscaloosa.....	232
.....do.....	Iron....	25	.....do.....	.....	Eutaw.....	.....do.....	*232a
.....do.....	.....	.....	.....	.....	Lafayette...	.....do.....	232b
.....do.....	Hard...	.....	.....	.....	Tuscaloosa .	.....do.....	*233
.....	.....	.....	.....	.....	.....	.....do.....	233a
Flows.....	Hard...	15	None apparent	.....	Lafayette...	.....do.....	234
Steam pump	.....	.....	.....	.....	.....do.....	.....do.....	234a
Air lift.....	Soft....	20	.....do.....	None.....	Creek bottoms.	Wilcox.....	*235
Pump.....	Iron and alkaline, soft.	100	.....do.....	.....	Lafayette? .	.....do.....	236
.....	Soft....	½	.....do.....	Easily lowered	.....do.....	Lafayette.....	237
Flows.....	....do...	1	.....do.....	.....	Alluvial....	Wilcox.....	*238
.....do.....	....do...	5	.....do.....	.....	River bottoms.	.....do.....	239
.....do.....	.....	5	.....do.....	.....	.....do.....	.....do.....	240
.....do.....	Soft....	.....	Slight.....	.....	.....do.....	Claiborne.....	241
.....do.....	....do...	34	None apparent	.....	Second river bottoms.	Wilcox.....	*242
.....do.....	....do...	5	.....do.....	.....	River bottoms.	.....do.....	243
.....do.....	....do...	.....	.....do.....	.....	.....do.....	.....do.....	244
Pump.....	Soft, alkaline.	.....	.....do.....	Lowered.....	.....	Tuscaloosa.....	244a
.....	.....	.....	.....	.....	Selma.....	Eutaw.....	*244b
Windmill...	Soft....	.....	.....	.....	.....do.....	.....do.....	*245
Hand pump	...do....	.....	.....	.....	.....do.....	.....do.....	*246
Flows.....	...do....	.....	.....	.....	Aluvium....	.....do.....	247
Windmill...	...do....	.....	None apparent	Slight.....	Selma.....	Tuscaloosa.....	248

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location.			Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
				Township.	Range.	Section.					
								In.	*Feet.*	*Feet.*	*Feet.*
*249	Noxubee	Macon	Mobile and Ohio R. R.	....	....	....	1898	3	769	730	+ 8
*250	do	do	A. T. Dent	15	17	33	1898	6–4	800	750	− 14
*251	do	Shuqualak	City	1	17	16	1899	6	910	910	− 10
252	Oktibbeha	Osborn	A. A. Montgomery	....	....	....	....	....	485	485	− 30
*253	do	Starkville	do	19	14	3	1900	8	908	....	−130
*254	do	do	Agricultural and Mechanical College.	18	14	3	1899	8	900	800	−129
*255	Panola	Batesville	City	....	....	....	1902	4	302	300	+ 20
256	do	Longtown	Dr. Crenshaw	7	9	6	1902	2	580	520	+ 0
*257	Perry	Barbara	A. J. Thomas	1	10	3	1897	12	72	62	− 62
*258	do	Brown	A. G. Brown	4	11	1	1892	6	43	38	− 0
259	do	Hattiesburg	People's ice factory	....	....	....	1900	6	335	....	− 0
260	do	do	M. Hemphill	....	....	....	1901	3	350	....	+ 25
261	do	do	City waterworks	....	....	....	1900	6–4	335	290	+ 30
262	do	do	J. J. Newman Lumber Co.	4	13	11	1899	6	368	368	+ 30
263	do	do	G. L. Hawkins	....	....	....	1898	2	380	375	+ 10
264	do	do	Gulf and Ship Island R. R.	....	....	....	1902	3	350	300	+ 30
265	do	do	Mike Dunn	....	....	....	1902	3	325	....	+ 0
266	do	Hecla	George Baylis	4	13	10	1897	2	600	....	+ 0
*267	Pontotoc	Ecru	Mobile, Jackson and Kansas City R. R.	....	....	....	1905	8	93	71	− 0
268	do	McLauren	J. A. Barrow	2	12	4	1897	12	52	48	− 48
269	do	do	R. A. Cooper	8	2	29	1902	6	216	216	+
270	do	do	V. B. Tucker	8	3	31	1898	6	62	62	+
271	do	Sherman	D. C. Longston	8	4	36	1899	....	250	250	− 40
272	Quitman	Belen	M. E. Denton	28	2	25	1901	2	840	800	+ 0
273	do	do	Turner Bros	28	2	28	1902	3	860	810	+ 0
274	do	do	do	28	1	29	1902	2	724	650	+ 50
275	do	Lambert	Quitman Developing Co.	27	1	22	1904	2	720	680	+ 30
276	do	do	Quitman County Developing Co.	27	1	15	1904	2	690	560	+ 10
277	do	do	Bacon Nolan Co	26	1	15	1904	2½	700	650	+ 40
*278	do	Riverside	L. Marks	28	1	35	1901	2	636	600	+ 40
279	do	Sumner	Bell & Lawrence	25	1	10	1904	2	650	600	+ 30
280	Scott	Forest	O. B. Triplett	6	8	16	1896	3	220	220	− 9
*281	Smith	Taylorsville	Thomas James	10	14	17	1902	6	1,135	1,100	+ 0

* See text, pp. 36–38, for additional data.

MISSISSIPPI—Continued.

the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing stratum.	No.
		Gals.					
lows	Soft	5	None apparent	Lowered	Selma	Tuscaloosa	*249
ump	do		Little	Lowers 16 feet	do	do	*250
do	Alkaline, soft.		None apparent	Little	do	do	*251
					do	do	252
ompressed air.	Soft	145	None apparent	Slight	do	do	*253
do	Soft, alkaline.	145	Neither	do	do	do	*254
lows	Hard	60	None apparent		Port Hudson.	Wilcox	*255
do	do	50			do	do	256
ucket	do				Lafayette	Lafayette	*257
	do	100			do	Grand Gulf	*258
ucket	Soft		None apparent		Second river bottom.	do	259
lows	do	Few	do		Lafayette	do	260
do	do	250	None	Slight	Second river bottom.	do	261
do	Hard	250	Small decrease		do	do	262
do	Soft	Few	None apparent		Lafayette	do	263
do	do	150	do		Second river bottom.	do	264
do	do		None		do	do	265
do	Hard	100			Lafayette	do	266
ucket	do				do	do	*267
ook-pump.	Soft	120	Decreased	Lowered 3 feet in 6 hours.	Ripley	Ripley	268
lows	do	20			Lafayette	do	269
do	Hard	1½			Ripley	do	270
ump					Lafayette	do	271
	Soft	20	Decreased		Alluvium	do	272
lows	do	60	None apparent		Port Hudson.	Wilcox	273
do	do	55	do		do	do	274
do	do	52	Neither		do	do	275
do	do	60	Increased		do	do	276
do	do	100	do		do	do	277
do	do	60	None apparent		do	do	*278
do	do	40	Same		do	do	279
		10			Lafayette	Jackson	280
lows		6			do	Grand Gulf	*281

DEEP-WELL RECORDS

Partial list of deep wells

No.	County.	Town.	Owner.	Location.			Year completed.	Diameter of well.	Depth of well.	Depth to principal water supply.	Height of water above (+) or below (−) mouth of well.
				Township.	Range.	Section.					
								In.	*Feet.*	*Feet.*	*Feet.*
282	Sunflower	Belmont	State						1,000	1,000	+
*283	do	Dockery	Will Dockery	22	4	33	1901	2½	929	929	+35
284	do	Doddsville	R. E. Dodds	21	3	29	1900	2	820	820	+70
285	do	Indianola	City				1904	4	1,320		+49
286	do	do	W. B. Martin	19	4	31	1900	3	1,300	1,260	+
*287	do	Moorhead	Chester H. Pond	18	3	4	1899	2	936	936	+45
288	do	Ruleville	Chas. Campbell	22	3	31	1900	3	864	820	+
289	do	do	Rule Bros	22	3	31	1900	2	865	700	+70
290	do	Sunflower	R. C. Burroughs	19	3	5	1889	1½	880	880	+
291	Tallahatchie	Albin	Jerry Robinson	24	1	29	1900	3	517		+
292	do	Charleston	J. W. Saunders	25	2	26	1901	2½	760	545	+18
293	do	do	M. P. Webb	24	2	15	1901	2	420	420	+
294	do	do	W. G. Harvey						450	450	+10
295	do	Crevi	C. W. Neilson	26	2	10	1902	2	400	380	+
296	do	Glendora	E. D. Graham	23	12	28	1898	2	465	420	+
297	do	Sharkey Landing.	T. G. James	24	1	35	1899	3	450	390	+
298	do	Sumner	I. B. Dudley	24	2	11	1901	2	552		+
299	do	Swanlake	W. A. Hawkins	23	1	10	1901	2	582		+
300	do	Webb	E. B. Taylor	24	1	18	1899	2	512	480	+
*301	Tate	Staghorn	S. T. Clayton	5	9	21	1901	30	110	107	−
302	Tippah	Dumas	A. C. Anderson	4	5	13	1901	40	60	55	−55
*303	Tunica	Tunica	City						865	865	+ 0
304	do	Commerce	R. F. Abbey	4	11	32	1900	2½	865		+
*305	do	Longtown						2	521	471	+
*306	Union	New Albany	City						230	230	+40
*307	Washington	Leland	do	18	7	15	1900	6	512	452	−14
308	Wayne	Red Bluff	do				1900	3½	265		+ 5
*309	do	Waynesboro	do	8	7	12	1900	4	525		+10
310	do	do	Ice factory	8	7	12	1902	4	520		+10
311	do	do	Turpentine distillery	8	7	12	1902	4	525		+10
312	Webster	Walthall	J. L. Lamb	21	10	30	1898	6			+20
313	Winston	Louisville	W. C. Hight	15	12	27	1870	36	42	32	−32
314	Yalobusha	Coffeeville	J. A. Aston				1901	2	250	230	+ 1½
*315	do	do	W. C. Bryant	24	6	28	1903	2	238	238	+10
316	do	do	W. H. Bailey	24	6	4	1899	2	160	145	+12
317	do	do	J. F. Proovin	24	6		1901	2	275	250	+ 5
*318	do	Water Valley	City	11	4	5	1897	6	60	40	−12
*319	Yazoo	Yazoo	do				1905	6	1,577		
320	do	Sartartia	M. King	10	3	31	1898	3	588	588	+

* See text, pp. 38-39, for additional data.

IN MISSISSIPPI—Continued.

in the State of Mississippi—Continued.

How obtained at surface.	Quality.	Supply per minute.	Increase or decrease of supply.	Effect of pumping on level of water.	Geologic horizon of well mouth.	Geologic horizon of principal water-bearing statum.	No.
		Gals.					
Flows		250			Port Hudson.	Claiborne	282
do		80			do	do	*283
do		80			do	do	284
do		200			do	do	285
do	Alkali	20			do	do	286
do		20			do	do	*287
do		100	Neither		do	Wilcox	288
do		75	do		do	do	289
do		50			do	do	290
do		25			do	do	291
do		32			do	do	292
do		50			do	do	293
do		25			do	do	294
do		40			do	do	295
do		60			do	do	296
do		50			do	do	297
do		12			do	do	298
do		75			do	do	299
do		75			do	do	300
Windlass					Lafayette	do	*301
Bucket					do	Ripley	302
Flows	Soft	200	Neither		Port Hudson.	Wilcox	*303
do	do		do		do	do	304
do	do	3	do		do	do	*305
do		15			do		*306
Pump	Soft		Same	None	Port Hudson.	Claiborne	*307
Flows	do		do		Vicksburg	do	308
do	do	25	do		do	do	*309
do	do	20-40	Variable		do	do	310
do	do	25	None apparent		do	do	311
do		60			Lafayette	Wilcox	312
Bucket					do	do	313
Flows		1½			do	do	314
do		25			do	do	*315
do					do	do	316
do		2			do	do	317
Steam pump					do	do	*318
		14			Alluvium	Claiborne	*319
					Port Hudson.	do	320

SELECTED RECORDS IN DETAIL.

[Numbers in heavy-faced type refer to preceding table.]

10. *Record of city wells at Corinth, Alcorn County.*

[Authority, city waterworks.]

		Feet.
Common soil		15
Blue clay	Selma chalk	20
Sand	Selma chalk	30
Hard rock	Selma chalk	1
Sand, water bearing		35
Hard shale, clay, and fine sand, Eutaw-Tuscaloosa		200
Sandstone, limestone, and shale (Chester and St. Louis)		135
Siliceous rock ("flint rock"), Tullahoma		115

12. *Record of city well at Kosciusko, Attala County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay and sand	30	30
Black clay	10	40
Black clay and rock	25	65
Rock, greensand, and shells	25	90
Sand and shells	60	150
Black dirt (lignite)	50	155
Gray sand	40	195
Black clay and gray sand	50	245
Gray sand, black clay, and rock	30	275
Water-bearing sand	5	280

Water is found at 35 feet, 75 feet, 195 feet, and 275 feet. Water rises to 75 feet of surface.

Record of shallow well in sec. 36, T. 20, R. 8 W., Bolivar County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1870.]

	Thickness (feet).	Depth (feet).
Surface loam	3	3
Sand, as seen freshly deposited by Mississippi River	3	6
Black buckshot clay	30	36
Red clay, source of water		36

The above is an open dug well. As soon as the red water-bearing clay was reached the water rushed in so rapidly that the digger had hardly time to get out before the well was filled. Water rises to within 15 feet of the surface.

Record of well in sec. 19, T. 19, R. 5 E., Carroll County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1870.]

	Thickness (feet).	Depth (feet).
Surface soil.		
Variegated clay	16	16
Indurated ledge of ferruginous sand, with seams of crystalline salenite alternating with layers of greensand	4	20
Greensand	9	29
Indurated ledge of ferruginous sand alternating with layers of greensand, as above	4	33
Hard rock, which effervesced in places	3	36
Siliceous, indurated greensand, with shells	6	42
Light-yellow sand, with ledges of indurated sand, containing concretions of sandstone, also clay nodules embedded in the sand	6	48

Strong mineral water was obtained at 44 feet.

20a. *Record of railroad well at Okolona, Chickasaw County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil, gravel, and clay	20	20
Blue limestone (Selma chalk)	300	320
Hard sand rock	3	323
Sand rock	100	423
Greensand, soapstone, and water	50	473
Soapstone	75	548

Water rises within 22 feet of surface.

21a. *Record of well at Hermanville, Claiborne County.*

[Authority, W. G. Herrington, driller.]

	Total depth (feet).
Red clay Gray clay Sand rock Hard blue clay (hardpan) Fine blue sand, which supplies abundant water	86

25. *Record of town well at Enterprise, Clarke County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand	6	6
Clay and sand	10	16
Quicksand	6	22
Hard blue rock	½	22½
Blue soapstone	97½	120
White sand and blue rock	25	145
Soft soapstone	7	152
White sand and gravel	4	156

35. *Record of Weems well at Shubuta, Clarke County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand and clay	25	25
Marl	125	150
Marl, clay, and sand	272	422

Water flows above surface.

52. *Section of town well at West Point, Clay County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and loam	20	20
Limestone (Selma chalk)	180	200
Sand and clay	400	600

Water flowed at first, but does not now.

52a. *Record of town well at Cedar Bluffs, Clay County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and loam	10	10
Limestone (Selma chalk)	450	460
Hard rock	2	462
Sand and water	188	650

Water rises within 100 feet of surface.

Record of well 3 miles south of Grenada, Grenada County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet)
Clay	10	10
Sand	30	40
Soapstone	30	70
Sand	10	80
Soapstone (clay)	10	90
Mud	20	110
Soapstone (clay)	10	120
Very coarse sand	95	215
Hard rock	0.25	215.25
Sand	10	225.25
Soapstone (clay)	335	560.25
Two thin rocks	0.75	561
Soapstone (clay)	40	601
Water-bearing sand	63	664
Soapstone	20	684
Water-bearing sand	37	721

Well flows one-half gallon per minute.

56a. *Record of city well at Grenada, Grenada County.*

	Thickness (feet).	Depth (feet).
Surface loam	60	60
Sand	30	90
Soapstone (clay)	30	120
Sand and soft clay	40	160
Soapstone (clay) with sand	90	250
Blue sand	30	280
Soft stone (clay?)	30	310
Soft blue sandy rock, very fine	140	450
Soft clay	10	460
Sand and water	30	490
Soft blue sandy rock	110	600
Rock	20	620

At a depth of 250 feet water rose within 6 feet of surface; at 490 feet the well overflowed.

Record of well 1 mile north of Bay St. Louis, Hancock County.

[Begun October 29, 1904; completed November 20, 1904. Authority, John L. Ford, driller.]

	Thickness (feet).	Depth (feet).
Blue sandy clay	10	10
White sand	50	60
Yellow sand	35	95
White sand and gravel	50	145
Green clay	15	160
Gray sand	60	220
Green clay	130	350
Gray sand	20	370
Green clay	280	650
Water sand, flows 50 gallons per minute	40	690
Blue clay	128	818
Water sand, flows 225 gallons per minute	79	897

Diameter of well, 3 inches. (From Bull. U. S. Geol. Survey No. 264.)

Generalized section of wells between Biloxi and Pass Christian, Harrison County.

[Authority, A. Dixon.]

	Feet.
Sand	80
Clay	125
Sand and clay	425
Light-gray fine sand	500
Clay	600
Water-bearing sand	685

Record of well at Quarantine Station, Ship Island.

[Authority, Dr. P. C. Kallock in Underground Waters of Louisiana (Harris).]

	Thickness (feet).	Depth (feet).
White sand	45	45
Soft clay and mud	155	200
Hard blue clay	100	300
White sand	5	305
Blue clay	260	565
Sandstone	½	565½
Blue clay	156	721½
Water-bearing sand	9	730½

112. *Record of well at Howison, Harrison County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Red clay	100	100
White sand	100	200
Blue clay	1,200	1,400
Water-bearing sand	80	1,480

Water rises within 35 feet of surface.

Log of deep well at State Penitentiary, Jackson, Hinds County.

[Authority, E. W. Hilgard.]

	Thickness (feet).	Depth (feet).
Surface materials and clay marl	20	20
Blue sandy shell marl	11	31
Dry sand, with streaks of whitish or gray clay containing impressions of leaves	80	111
Wet quicksand, caving very badly	70	181
(Here water rose to within 70 feet of surface.)		
Black clays, mostly laminated, interstratified with layers of sand. Fragments of impressions of leaves, and, at 400 feet, a catkin of a willow were bored up	268	449
Greensand, with shells and streaks of gray and red clay	30	479
Water-bearing sand, caving badly	20	499
(Here water rose to within 50 feet of surface.)		
Greensand with shells, same as above	?	
Ledge of gray fossiliferous limestone	1	500
Blue clay, with calcareous nodules and some layers of greensand marl	12	512
Shell marl, with layers of black clay	10	522
Quicksand, with a great deal of mica	5	527
White indurated clay, with iron pyrites, not yet passed through	?	

Record of Alabama and Vicksburg Railroad well at Smiths, Hinds County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and clay	44	44
Limestone and sandstone	104	148
Thin strata of hard rock	4	152
Rock and sand	394	546

Water rises within 23 feet of surface; capacity, 113 gallons per minute; mouth of well about 130 feet above sea level.

Generalized section of wells on Deer and Silver creeks, Issaquena County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1870-71.]

	Thickness (feet).	Maximum depth (feet).
Top clay	4-10	10
Sand	20-30	40
Blue mud (clay)	10-20	60
Light, fine sand	2-4	64

Pebble bed, containing water.

The above section was given by Mr. I. W. Blessing, who had driven about 70 wells along the above-mentioned creeks. The sand above the pebbles is in very fine, smooth, rounded grains, and comes up with the water when the well is pumped. The pebbles in the bed from which the water comes are often cemented together, forming a hard conglomerate.

167. *Record of well near Moss Point, Jackson County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand	100	100
Clay and mud	150	250
Hard clay	150	400
Water-bearing sand	20	420
Hard clay	200	620
Water-bearing sand	40	660
Sand and clay	110	770
Water-bearing sand	44	814
Hard rock, sand, mud, and wood	736	1,550

Flowing water at 650 and at 800 feet.

181. *Record of city well at Scranton, Jackson County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand and gravel	350	350
Blue clay	400	750
Clam shells	5	755
Blue clay	25	780
Water-bearing sand	20	800

Well flows 150 gallons per minute.

Record of well at Ocean Springs, Jackson County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface soil, sand, and gravel	150	150
Clay	250	400
Sand	20	420
Clay	40	460
Sand and gravel	60	520
Clay	400	920
Water-bearing sand	30	950

Water flows 250 gallons per minute.

Record of well 1½ miles northwest of Moss Point, Jackson County.

[Begun October 3, 1904; completed October 12, 1904. Authority, John L. Ford, driller.]

	Thickness (feet).	Depth (feet).
Hard, yellow clay (sandy)	20	20
Yellow sand	15	35
Clay (sandy, variegated)	15	50
Sand (fine, white)	50	100
Sand (coarse, white)	40	140
Clay (sandy)	70	210
Sand (fine, white)	10	220
Clay	150	370
Sand (fine, white)	20	390
Clay	320	710
Sand (fine, gray)	80	790
Clay		790

Main water supply 770 to 790 feet. Yield, 135 gallons per minute. (From Bull. U. S. Geol. Survey No. 264.)

Record of city well at Ellisville, Jones County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Sand and gravel	80	80
Green clay	280	360
Sand	10	370
Green clay	230	600
Sand rock	12	612
Greenish marl	288	900
Shell rock	5	905
Green marl	195	1,100
Shells	5	1,105
Green marl	295	1,400

Record of city well at Oxford, Lafayette County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay and sand	90	90
Dry sand	15	105
Clay	67	172
Soapstone (clay)	78	250
Hard sandstone	50	300

Water rises to 70 feet of surface.

Record of well at Lumberton, Lamar County.

[Authority, W. N. Logan and W. R. Perkins.]

	Depth (feet).
Coarse sand and some gravel	40
Fine sand	85-90
Fine sand and white clay	103
Hard white clay	110
Soft but fine sand	180
Hard white clay	200
Hard and soft spots, water white	210
Hard white clay, pipe goes 28 inches per hour	277
White water	314
Blue mud	512-528
Blue mud, still in water	560
Hard clay, white water	620
Very soft rock	670
Very soft white clay	682
Hard clay	720
Blue clay	760
Hard rock	770
Softer rock	784
Bluish rock	830
Hard rock	850
Sand	860

The well was drilled to a depth of 1,800 feet.

Record of cotton-mill well No. 1, Meridian, Lauderdale County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	14	14
Sand	16	30
Clay	6	36
Shale	14	50
Sand	1	51
Lignite	2	53
Sand	3	56
Shale	2	58
Pipe clay	19	77
Lignite	6	83
Pipe clay	7	90
Sand	2	92
Clay	3	95
Sand	4	99
Clay	22	121
Sand	5	126
Clay	5	131
Sand	5	136
Blue clay	4	140
Sand	1	141
Blue clay	18	159
Sand	9	168
Lignite	5	173
Sand	2	175
Lignite	4	179
Sandstone	1	180
Clay	7	187
Sand	27	214
Lignite and clay	8	222
Clay	2	224
Sand	2	226
Lignite	2	228
Sand	27	255
Clay	12	267
Lignite	4	271
Clay	27	298
Sand	4	302
Clay	4	306
Sand	6	312
Clay	5	317
Pyrites rock	1	318
Sand	3	321
Clay	7	330
Lignite	2	332
Clay	15	347
Sand	43	390

Water rises within 40 feet of surface.

Record of well in sec. 11, T. 9, R. 8 E., Leake County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1871.]

	Thickness (feet).	Depth (feet).
Red clay, with a little sand	6	6
Variegated clays, containing shells	10	16
Light-colored, fossiliferous rock which effervesces with hydrochloric acid	1	17
Variegated clays, as above	9	26
Yellow sand to water	26	52

Record of well at Mooresville, Lee County.

	Thickness (feet).	Depth (feet).
Selma chalk	155	155
Eutaw sands, source of water	20	175

205a. *Record of Brick and Tile Company's well at Baldwyn, Lee County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil, clay, and sand	40	40
Limestone (Selma chalk)	74	114
Clay and sand (Eutaw)	220	334
Water-bearing sand	46	380

Water rises within 5 feet of surface.

212b. *Record of Mobile and Ohio Railroad well, Tupelo, Lee County.*

[Authority, M. & O. R. R. Co.]

	Thickness (feet.)	Depth (feet).
Sand and gravel	15	15
Limestone } Selma chalk	200	215
Hard rock } Selma chalk	1	216
Soft rock } Selma chalk	150	366
Greensand, water-bearing	40	406
Clay	30	436

Water flows above surface.

Record of T. B. Minyard's well, at Greenwood, Leflore County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and clay	15	15
Mud and silt	140	155
Soapstone (clay)	200	355
Greensand, with the strata of hard rock	20	375

221a. *Record of well at Minter City, Leflore County.*

[Authority, C. E. Feigler, driller.]

	Thickness (feet).	Depth (feet).
Surface soil	10	10
Sand	100	110
Gravel	10	120
Sand	80	200
Soapstone and pipe clay interbedded with sand to bottom of well	237	437

225a. *Record of railroad well at Columbus, Lowndes County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay, sand, and gravel	25	25
Sandstone	300	325
Greensand and clay	95	420

225b. *Record of railroad well at Artesia, Lowndes County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	10	10
Limestone (Selma chalk)	350	360
Hard sandstone	2	362
Soft sandstone and soapstone	175	537
Clay and sand	60	597

Water rises to within 18 feet of surface.

Record of well at Canton, Madison County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface sand and clay	150	150
Clay	175	325
Water-bearing sand	30	355
Clay	60	415
Water-bearing sand	30	445

Record of well in sec. 2, T. 7, R. 2 E., Madison County.

[Authority, E. W. Hilgard.]

	Thickness (feet).	Depth (feet).
Surface materials and bluish and yellowish clay marls	40	40
Blue clay marl, poor in shells	40	80
Blue sandy shell marl, with well-preserved shells	10	90
Dark-colored, mostly bluish, laminated clays interstratified with layers of sand	185	275
Hard gray sandstone	½	
Yellow water-bearing sand	15	290
(Here water rose to within 75 feet of surface.)		
Dark-colored sandy clay, with crystals of gypsum	85	375
Hard gray sandstone	½	
Lignite, interstratified with layers of clay; above it a stream of water rising to within 45 feet of surface (as far as penetrated)	40	375 415

230. *Record of town well at Holly Springs, Marshall County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Reddish clay (Columbia)	20	20
Red sand (Lafayette)	87	107
Sand rock	1	108
Clay	52	160
Hard sandstone	½	160½
Clay and sandstone	139½	300
Fine sand, water bearing	40	340
Pipe clay	13	353
Coarse sand	4	357
Sticky clay	43	400

General section of wells in river bottom near Aberdeen, Monroe County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface soil and loam	15	15
Sandstone	200	215
Sand and first water	35	250
Clay and lignite	100	350
Sand and water	30	380

232a. *Record of well at Amory, Monroe County.*

[Authority, A. F. Crider; section obtained from old well driller.]

	Thickness (feet).	Depth (feet).
Lafayette sand	12	12
Lafayette gravel	6	18
Gray sand, water bearing	1	19
"Soapstone," or joint clay, with thin layers of shelly sandstone. The clay caved when drilling well and had to be cased	115	134
More compact clay, which required no casing in drilling	65	199
Sand, source of water.		

Water was obtained in sand below the compact clay. It flows at rate of 20 to 25 gallons per minute from a 2½-inch pipe. The water is highly impregnated with iron oxide. The pipe and gutter which carry the water from the well are covered with a thick coating of iron oxide. The same driller reports that a second stream of water is present here at a depth of from 240 to 250 feet.

Well at Gattman, Monroe County.

[Authority, W. F. Riley, owner.]

	Thickness (feet).	Depth (feet).
Sandy yellow clay	18	18
Fine sand (quicksand)	65	83
Gravel and sand	4	87
Yellow sand Gray sand Blue clay Deep-red clay Lignitic clay Sand	113	300
Hard grayish sand rock	2	302
Fine sand or opening from which water rose to surface, furnishing about 2 gallons per minute	6	308
Small, round gravel, about the size of large shot	3	311
Hard gray sandstone (hard as millstone), becoming softer and darker in color below. Water rose to surface from this soft sandstone	312	623

Water flows above surface at the rate of 15 gallons per minute, is full of gas bubbles, and has a taste of borax and soda.

235. *Record of well at Winona, Montgomery County.*

[Authority, Robert A. Allison.]

	Thickness (feet).	Depth (feet).
Soil and clay	25	25
Orange-colored sand	10	35
Blue marl	40	75
Lignite	5	80
Quicksand	15	95
Black clay	50	145
Coarse sand, containing fair supply of water	10	155
Lignite	10	165
Blue marl	35	200
Fine sand	15	215
Clay	10	225
Quicksand	60	285
Clay	40	325
Fine sand, coarse on top	25	350
Brown clay	35	385
Coarse sand, gravels on top	27	412

Water is obtained in the lowest layer of coarse sand and gravel at a depth of 395 feet. About 25 or 30 wagonloads of sand were pumped from the well during the first three or four days. After that the sand ceased to rise, and the well now furnishes an abundant supply of water, which is not perceptibly lowered with an air-lift pump. Water is clear and free from minerals, and is reported to have a temperature of 65° F.

244b. *Record of railroad well at Brookville, Noxubee County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	8	8
Limestone (Selma chalk)	450	458
Hard sand	4	462
Soft sand	150	612
Greensand and water	45	657

The water rises within 60 feet of surface.

245. *Record of well at Cliftonville, Noxubee County.*

[Authority, J. B. Cunningham, driller.]

	Thickness (feet).	Depth (feet).
Selma chalk	300	300
Greensand	20	320
White sand	20	340
Greensand	10	350
White sand	40	390
Ferruginous sandstone	1	391
Dark greensand, *source of water*	60	451

246. *Record of well at Ravine, Noxubee County.*

[Authority, J. B. Cunningham, driller.]

	Thickness (feet).	Depth (feet).
Selma chalk	250	250
Greenish-colored sand (Eutaw)	475	725

249. *Record of Mobile and Ohio Railroad well, Macon, Noxubee County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	8	8
Limestone (Selma chalk)	600	608
Hard sandstone	3	611
Soft sandstone	65	676
Greensand and water	40	716
Soapstone	53	769

251. *Record of Shuqualak well, Noxubee County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	10	10
Limestone (Selma chalk)	750	760
Sandstone	100	860
Greensand and water	50	910

Water rises within 10 feet of surface.

254. *Record of well at Starkville, Oktibbeha County.*

[Authority, Bulletin of the Mississippi Agricultural and Mechanical College, vol. 1, No. 2, page 10.]

	Thicknes (feet).	Depth (feet).
Surface soil	14	14
Selma chalk	749	763
Shell rock	4	767
Clay (sandy)	24½	791½
Shell rock	7	879½
Sand (micaceous)	56	854½
Clay	10	864½
Sand	35½	900

Water rises within 150 feet of the surface.

255. *Record of town well at Batesville, Panola County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface	10	10
White sand	25	35
Blue clay	10	45
Clay and sand	215	260
Rock	2	262
Water-bearing sand	40	302

Water rises 20 feet above the surface; flows 50 gallons per minute.

257. *Record of well at Barbara, Perry County.*

[Authority, A. J. Thomas, owner.]

	Thickness (feet).	Depth (feet).
Red surface clay	40	40
Coarse sand and sandstone	2	42
Blue pipe clay	7	49
Yellow sand	13	62
White sand and sandstone	10	72

General section of wells at Hattiesburg, Perry County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Pinkish clay	100	100
Water and sand	30	130
Greenish clay	150	280
Water-bearing sand and gravel	20	300

There are about 25 wells in the town flowing from 5 to 50 gallons per minute.

258. *Record of well at Brown, Perry County.*

[Authority, A. G. Brown, owner.]

	Thickness (feet).	Depth (feet).
Red clay	20	20
Variegated sand, of white, red, and yellow color, with occasional thin layers of "rock"	23	43

Water obtained at 38 feet.

267. *Record of well at Ecru, Pontotoc County.*

[Authority, Albert Goldsbury, driller.]

	Thickness (feet).	Depth (feet).
Red clay and loam	23	23
Blue clay	27	50
Hard limestone	4	54
Reddish muddy sand	5	59
Shell marl	1	60
Sand	3	63
Reddish sand, water-bearing	10	73
Gray clay to bottom of well	20	93

Diameter of well, 6 inches. Water barely flows over surface, and is raised to tank by steam pump. It is clear, and is used in locomotive boilers.

278. *Record of L. Marks's well at Riverside, Quitman County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Blue mud	40	40
Mud and water-bearing sand	45	85
Water-bearing sand and gravel	50	135
Sand and gravel	40	175
Soapstone (clay)	220	395
Rock	½	395½
Soapstone (clay)	50	445½
Rock	½	446
Greensand	10	456
Lignite	1	457
Soapstone (clay) and water-bearing sand	179	636

Record of town well at Forest, Scott County.

[Authority W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Mud and gumbo	60	60
Black mud	15	75
Grayish sandy clay	25	100
Gray sand and iron pebbles	50	150
Lime rock	40	190
Sandy rock	5	195
Dark-gray hard rock	22	217
Water-bearing sand	2	219

Water rises within 90 feet of surface.

Record of well in sec. 8, T. 10, R. 7 W., Sharkey County.

[Authority, unpublished notes of E. A Smith, assistant geologist of Mississippi, 1870.]

	Thickness (feet).	Depth (feet).
Sandy loam	20	20
Dark, sticky clay		
Buckshot clay	10	30
Fine, sticky, sandy clay, containing water		30

281. *Record of well at Taylorsville, Smith County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Grayish-brown clay	100	100
Blue clay	200	300
Sand, gravel, and water	15	315
Brownish clay	85	400
Hard rock	23	423
Sand	3	426
Brownish clay	704	1,130
Brown sand, very fine	5	1,135

Water flows 10 gallons per minute.

283. *Record of well at Dockery, Sunflower County.*

[Authority, Will Dockery, owner.]

	Thickness (feet).	Depth (feet).
White sand	60	60
Gravel and sand	115	175
Quicksand with strata of clay about 50 feet apart; flowing water	600	775
Sand rock in layers 18 inches to 2 feet thick interbedded with sand	25	800
Greensand interbedded with rock	129	929

294. *Record of well at Charleston, Tallahatchie County.*

[Authority, W. G. Harvey, owner.]

	Thickness (feet).	Depth (feet).
Sands, silts, and clays	200	200
Sandstone rock	10	210
Lignite and lignitic clays	140	350
Quicksand	100	450

Water rises 8 to 10 feet above the surface. Capacity, 25 gallons per minute.

Record of town well at Charleston, Tallahatchie County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay and blue mud	50	50
Sand	40	90
Soapstone (clay)	100	190
Hard white rock	2	192
Water-bearing sand	100	292
Soapstone (clay)	30	322
Water-bearing sand	40	362

Well flows 32 gallons per minute.

301. *Record of well at Staghorn, Tate County.*

[Authority, S. T. Clayton, owner.]

	Thickness (feet).	Depth (feet).
Surface clay	20	20
Gravel and sand	15	35
Red sand which changes to white sand	75	110
Pipe clay and sand, furnishing water		

Water rises but a few feet in the well.

Record of well at Senatobia, Tate County.

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Clay	24	24
Coarse gravel	15	39
Quicksand	21	60
Clay	4	64
Sand	10	74
White clay	2	76
Sand	14	90
Pipe clay	2	92
Water-bearing sand	28	120

Water stands within 40 feet of the surface.

303. *Record of well at Tunica, Tunica County.*

[Authority, W. J. Brigham.]

	Thickness (feet).	Depth (feet).
Alluvial sand and clay	15	15
Fine silt, sand, and clay	75	90
Fine white sand	250	340
Sand and gravel with layers of lignite Sand Hard, impervious clay White sand containing water	525	865

Water is soft and flows above surface.

305. *Record of well 5 miles west of Longtown, Tunica County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Soil and clay	30	30
Sand	110	140
Pipe clay	260	400
Rock	1	401
Sand	10	411
Soapstone (clay)	60	471
Sand and water	50	521

Water flows 15 gallons per minute.

306. *Record of well at New Albany, Union County.*

[Authority, Ed. Baker, driller.]

	Thickness (feet).	Depth (feet).
Surface clay	20	20
Calcareous sandstone	4	24
Clayey sand, water bearing	15	39
Blue sandy marl containing shells, with strata of limestone 3 to 4 feet thick at occasional intervals	165	204
White sand, source of water	20	224

307. *Record of city well at Leland, Washington County.*

[Authority, E. F. Turner, chairman of water committee.]

	Thickness (feet).	Depth (feet).
Buckshot clay	2	2
Fine sand	138	140
Gravel	14	154
Hard blue clay, containing six strata of sandstone rock, ranging in thickness from 6 inches to 2 feet	298	452
Coarse gray sand	60	512

Analysis of the above water is reported to have given 154.1 parts per million of solid matter, 119.8 of which were soda.

309. *Record of town well at Waynesboro, Wayne County.*

[Authority, W. N. Logan and W. R. Perkins.]

	Thickness (feet).	Depth (feet).
Surface clay	30	30
Sand and water	150	180
Marl and clay with flint "bowlders"	300	480
Water-bearing sand	20	500
Clay	25	525

Water flowed above surface from 180 feet.

318. *Record of well at Water Valley, Yalobusha County.*

[Authority, R. F. Kimmons, mayor.]

	Thickness (feet).	Depth (feet).
Common surface clay	12	12
Water-bearing sand	15	27
Stiff pipe clay	18	45
Water-bearing sand	15	60

The city of Water Valley has nine wells similar to the above, which furnish 500,000 gallons of water per day. Water stands within 12 feet of the surface. Six of the wells have furnished the above amount of water without any appreciable variation. All the wells are dug within a radius of 100 feet.

Record of well in sec. 23, T. 14, R. 4 W., Yazoo County.

[Authority, unpublished notes of E. A. Smith, assistant geologist of Mississippi, 1870.]

	Thickness (feet).	Depth (feet).
Surface soil	2½	2½
Red clay	6	8½
Buckshot clay Blue mud	21½	30

Water is warm and has slight mineral taste.

SANITARY ASPECT OF WELLS.

There is a widespread popular belief that clear, cold water coming from any kind of well is pure and wholesome, and until recent years the open well has been considered one of the most valuable adjuncts of the home or farm. In reality, however, wells of the open type are especially liable to pollution and may be the source of disease. On many premises the open well is in the lowest ground, and above it on the slopes are barns, outhouses, and dwellings. Such a case is illustrated in Pl. VI, *B*. The lowest ground is chosen for the well because water is found there at less depth than elsewhere. The fact that the impurities from the sources mentioned are carried both by the surface water after each rain and by underground seepage downward in the direction of the well is commonly lost sight of. Water laden with impurities may either enter the top of the well, where this is unprotected by embankments, or it may enter through the wood, brick, or stone curbing. The pollution of the well by seepage is especially likely to occur where the soil is porous and the well shallow, and, in limestone regions, where open underground channels exist.

It is not infrequently the case that open wells are left uncovered, so that impurities carried by the winds are free to settle through the open mouth. Where covered, the top of the well is often but little above the ground level, and the covering is made of unjointed planks loosely thrown down and having large openings between them. Wooden curbs, which in dry weather shrink and later admit much surface water to the well, are in common use. Chickens and pigs tramping around the barnyard and open privies and workmen from the barnyard or manured fields often carry filth on their feet. The first shower of rain or the drippings from the well bucket may carry these poisonous germs into the well. There are numerous instances in Mississippi where little cesspools have been dug in the ground near the wells and are kept filled with water for chickens, ducks, turkeys, and pigs. This water becomes highly polluted and more or less of it sinks into the earth and finds its way directly into the well.

A. OUTFIT FOR DRIVING TUBULAR WELLS.

Such wells are ordinarily safe, as the shallow polluted waters are shut off.

B. A COMMON BUT HIGHLY DANGEROUS WELL LOCATION NEAR BARNS AND OUTHOUSES.

Drainage is toward well. Photograph by M. L. Fuller.

When in health the human body is resistant to disease, and polluted waters may be use for years without causing sickness; if, however, the human system for any reason become weakened, disease germs, if present, may rapidly develop. Many outbreaks of typhoi fever, both in this country and in Europe, have been traced to polluted wells or to mil distributed in cans washed in the water from them.

The well, if used for drinking water, should occupy a high point on the premises an should be so situated that polluted waters from any source can not run near it. If the we is an open one the upper part should be dome-like in shape and sealed with cement, with tightly fitting top, so that no impurities of any kind can get in.

Many who are accustomed to the open well have a prejudice against drinking water fro an iron pump. The driven, bored, and drilled wells have, however, many advantages ove the large dug wells, some of which are as follows:

1. There is less possibility of getting impurities into small-bore wells put down wit machinery.

2. There is always a possibility that rats, frogs, and other objectionable animals or matte such as filth from the barnyard, will get into an open well if the cover is left off in som unguarded moment. The well of small diameter which has a pump in it is sealed fro all small animals, bugs, and even dust. A few strokes of the pump will remove the wate which has been standing in the pipe and bring up water which is fresh and uncontaminatec

3. The well of small diameter, when properly made, shuts off all surface waters an objectionable seepage waters. If a good supply is found, all the objectionable waters abov and below should be cased off, so that only the desirable supply is admitted into the pip

The so-called "streams" of water in Mississippi and the entire Gulf embayment are occur in horizontal sheets of sand. These water-bearing sands are usually overlain b layers of clay which prevent the waters immediately above the clay from entering the sand below. Where this tough clay layer is penetrated by the drill the water from above wi flow down to the bottom of the well unless it is shut off. But when iron casing is put i packing can be placed between the outside of the pipe and the clay layer, thus sealing u the hole made by the drill and shutting off undesirable waters.

4. It is not possible to dig wells by hand to a very great depth, and in some instance. as in some localities in the Northeast Prairie and in the Yazoo Delta, it is impossible to di them to the desired source of water without putting in some kind of curbing. In th various artesian basins over the State artesian wells are obtained only by drilling or borin

If water runs through a sufficient amount of pure sand it will give up a considerable pa of its impurities. A large part of the surface of Mississippi is made up of such sand, whic serves as a natural filter for the waters. In the more hilly sections of the State this san contains such a small amount of decayed organic matter that waters even from the shallo wells in the Lafayette sands rarely show a trace of organic matter. The shallow wells ver seldom have any strong undesirable minerals in their waters, so that such wells in the rur hilly districts of the State furnish, as a rule, excellent drinking water.

Conditions are different in the Yazoo Delta and in the Northeast and Central prairie The delta is a low, recently formed land, made up of sands and clays containing a larg amount of decayed vegetation. The soil is very fertile and produces a vigorous growth c succulent plants, many of which grow up and decay in a year. Large quantities of fre ammonia, albuminoids, nitrates, and nitrites are thus set free, part of which are carried dow into the soil and thus come in contact with the waters, which rise within a few feet of th surface.

In the Northeast and Central prairies much of the surface sand has been removed, leavin a limestone-clay soil, which as a rule is barren of water.

ANALYSES.

Analyses of Mississippi waters, in parts per million.

DEEP WELLS.

Locality.	Name of well.	Sodium (Na).	Potassium (K).	Calcium (Ca).	Magnesium (Mg).	Sulphate radical (SO_4).	Chlorine (Cl).	Carbonate radical (CO_3).	Phosphate radical (PO_4).	Silica (SiO_2).	Iron and alumina (Fe_2O_3+Al_2O_3).	Iron (Fe).	Organic matter.	Authority.[a]
Aberdeen	Aberdeen	12.1	5.96	6.28	2.38	1.80	6.11	29.3	.....	11.9	18	.....	.....	A, p. 31.
Ackerman	Kramer	31.7	4.94	11.3	8.15	2.32	6.08	75.7	1.24	28.9	13.5	.....	.....	A, p. 110.
Agricultural college	College	222	4.73	5.22	.473	3.21	125	388	.....	3.39	.....	0.694	.....	A, p. 42.
Do	Muldrow's	291	13.6	8.28	4.49	1.17	175	505	.....	11.9	.....	1.38	.....	A, p. 43.
Amory	Amory	7.12	4.25	3.71	1.86	3.57	4.21	16.9	.....	8.38	11.1	.....	.....	A, p. 30.
Artesia	Railroad	232	7.66	8.44	1.96	.904	6.85	319	.....	18.4	1.99	.....	.....	A, p. 37.
Batesville	Batesville	5.98	3.45	2.71	2.48	4.72	5.46	13.1	.....	29.9	17.2	.....	.....	A, p. 99.
Biloxi	Well No. 1	56.1	.942	.535	.140	7.18	5.88	65.5	[b] 1.46	41	.748	.....	.....	A, p. 73.
Do	Waterworks	116	1.23	1.32	.259	4	2.82	.....	[b] 1.34	24	.798	.....	.....	A, p. 74.
Bolton	.....	121	7.2	19	5	55	35	140	.....	27	12	.....	39	B.
Brookhaven	Brookhaven	14.4	5.49	3.78	.939	2.28	.....	6.25	.....	11.7	.698	.....	.....	A, p. 67.
Canton	Waterworks	37.4	3.31	6.21	1.56	11.3	6.32	52	.....	56.1	1.14	.....	.....	A, p. 111.
Clarksdale	Well No. 1	161	3.05	.926	.325	1.13	44.6	176	[b] 2.81	38.7	1.30	.....	.....	A, p. 82.
Do	Well No. 2	112	4.12	41.5	18.2	1.14	19.6	237	[b] .121	16.7	1.65	.....	.....	A, p. 83.
Do	Well No. 3	8.98	2.73	45.4	29.5	2.18	6.83	148	[b] 1.27	30.6	5.93	.....	.....	A, p. 84.
Cleveland	Cleveland	254	3.73	1.07	.481	1.17	.....	331	[b] 6.92	18.1	6.99	.....	.....	Do.
Cliftonville	Cliftonville	64.6	1.60	1.43	.270	1.47	68.9	81.4	[b] 1.92	.204	1.75	.....	.....	A, p. 47.
Columbia	Columbia	12.7	4.64	4.17	.952	18	5.99	.....	[b] .534	38.3	1.20	.....	.....	A, p. 64.
Columbus	Main street	7.85	6.63	10.4	3.77	.101	3.79	37.5	.....	9.40	14.2	.....	.....	A, p. 35.
Do	Kaye	11.1	9.27	7.77	2.62	.534	8.84	29.6	.....	10.3	3.34	.....	.....	Do.
Do	Ice factory	11.8	7.21	9.13	3.10	.431	4.63	38.1	.....	9.88	9.08	.....	.....	A, p. 36.
Crawford	Crawford	249	11.3	10.2	3.87	13	135	227	.....	18.9	2.59	.....	.....	A, p. 38.
Dockery	.....	185	13	2.9	1.40	1.2	14.5	237	6.7	25	.9	.....	.....	C.
Doddsville	Doddsville	192	6.48	2.53	.497	3.57	3.79	254	([b])	20.6	2.49	.....	.....	A, p. 87.
Durant	.....	46	.....	65	6.6	54	39	106	([b])	20	.....	.....	.....	D.
Do	Durant, I. C. R. R. Co.	73.6	12.2	4.92	7.93	25.6	11.8	107	.339	25.6	.597	.....	.....	A, p. 103.

Enterprise	Town	107	12.6	2.64	.721	4.79	3.79	148	[b] 1.23	14.3	.748			A, p. 56.
Glendora	Sturdivant	122	1.96	1.11	.551	2.05	18.2	147	[b] 3.62	30.1	.847			A, p. 91.
Greenville	Greenville	123	2.68	.606	.595	1.85	32.4	135	[b] 2.14	24.9	.397			A, p. 93.
Greenwood		55		2.2	.63	5	3.5	70	([b])	34	2.9			D.
Do	McNeal	30.7	9.32	16.2	4.51	4.23	7.48	73.5		27.8	1.93			A, p. 93.
Do	City	36.8	6.40	10.6	3.01	2.18	4.19	71.4		31.3	.798			A, p. 94.
Grenada (depth 620 feet.).		166	4.3	3.7	1.5	1.2	90	150	3	11	1			
Gulfport	Railroad	49.6	3.93	1.28	.217	9.97	5.88	58.9	[b] 1.34	20.8	.390			A, p. 72.
Do	Pier	69.4	1.53	.963	.194	7.18	5.88	84	[b] 1.28	24.3	.599			Do.
Hattiesburg	Waterworks	8.95	5.24	6.42	2.39	8.73	6.32	20.5		34.9	1.35			A, p. 63.
Hickory	Hickory	54.4	4.39	13.9	4.11	.473	3.62	102	[b] .298	32.5	.839			A, p. 53.
Holly Springs	Holly Springs	10.8	2.34	6.42	2.04	.532	16	16.7		11.7	.199			A, p. 105.
Indianola	Well No. 1	272	2.72	.855	.308	.945	9.10	350	[b] 7.30	24.6	.998			A, p. 86.
Ittabena	Ittabena	92.5	4.85	4.06	1.68	3.16	4.98	124		28.4	2.59			A, p. 96.
Jackson	Jackson's	23.2	6.42	99.8	20.6	32.4	13.6	204		44.6	.787	138		A, p. 112.
Leflore	Pollard	40.4	7.51	11.8	5.76	.737	6.74	84.3		32.7	2.10			A, p. 109.
Leland	Leland	126	2.94	1.71	.259	1.44	25.5	147		25.3	1.50			A, p. 92.
Lexington	Oil mill	8.06	2.98	14.7	5.60	2.67	8.10	43		26.1	1.85			A, p. 102.
Do	Wilson	200	3.24	1.93	.409	1.35	5.49	257		39.2	1.15			Do.
Lyon (artesian)		143	3.3	1.1	.14	1.2	41	155	2.6	38	1.3			C.
Macon	Macon	363	32.2	9.20	3.47	[c] 1.83	400	180		11.9	.884			A, p. 45.
Macon, 2 miles E. of		326	7.46	4.99	2.10	.0287	328	231		10.	.998			A, p. 46.
Markville (artesian)		344	2	3.2	.66	6.9	4	447	4.1	47		.69		E.
Moorhead	Cotton factory	306	3.51	1.43	1.20	1.76	4.63	401	[b] 1.87	14.8	.657			A, p. 85.
Moss Point	Denny	190	1.36	1.64	.357	1.33	144	143	[b] 1.07	45.8	.798			A, p. 79.
Ocean Springs (artesian).		116	19	22	7.8	Trace.	111	146	([b])	43		8.5		B.
Ocean Springs	Ocean Springs	172	1.25	1.89	.325	2.75	100	143	1.11	21.9	.748			A, p. 77.
Pass Christian	Public	155	3.31	.499	.487	1.89	62	154	1.24	22.1	.698			A, p. 71.
Quitman	Quitman	37.3	5.74	30.1	7.10	3.59	4.63	110		36.7	.597			A, p. 59.
Riverside (artesian; 636 feet deep).		45	6.4	3.2	1.4	3.4	4.5	66		74	1.5			F.

[a] A=Miss. Agr. Exp. Station, Bull. No. 89. B=A. L. Metz, Tulane University. C=W. R. Perkins, Agricultural and Mechanical College of Mississippi. D=Illinois Central Railroad. E=B. W. Kilgore, Agricultural and Mechanical College of Mississippi. F=W. L. Hutchinson, Agricultural and Mechanical College of Mississippi. G=J. C. Mims, board of health, New Orleans, La.

[b] Phosphoric acid is taken as P_2O_5.

[c] Sulphuric acid is taken as SO_3.

ANALYSES—Continued.

Analyses of Mississippi waters, in parts per million—Continued.

DEEP WELLS—Continued.

Locality.	Name of well.	Sodium (Na).	Potassium (K).	Calcium (Ca).	Magnesium (Mg).	Sulphate radical (SO_4).	Chlorine (Cl).	Carbonate radical (CO_3).	Phosphate radical (PO_4).	Silica (SiO_2).	Iron and alumina (Fe_2O_3+Al_2O_3).	Iron (Fe).	Organic matter.	Authority.
Ruleville	Rule Brothers	182	3.63	1.50	.562	1.24	4.63	215	[a]5.06	18.6	0.947			A, p. 86.
Sardis	Railroad	19.9	1.40	1 4.14	1.44	3.47	19.2	18.3		14.2	.650			A, p. 99.
Scooba	Mineral	297	23.2	510	238	774	934	485		25	2.12			A, p. 51.
Scranton	Waterworks	223	1.50	2.07	.389	1.67	184	139	[a]1.28	21.3	.748			A, p. 78.
Senatobia	Senatobia	8.35	.959	5.06	1.67	2.45	7.82	15.2		15.2	.399			A, p. 101.
Shubuta		400	21	2	1.4	20	4.7	605		21	1.1			F.
Starkville	Starkville	291	8.35	5.11	2.59	1.17	170	510		11.9	([b])	.898		A, p. 40.
Sunflower	Sunflower	245	1.74	1.43	.895	2.13	4.63	320	[a]5.21	42.1	1.90			A, p. 88.
Taylorsville	Taylorsville	172	10.9	1.43	4.32	27.1	26.8	196	2.14	17	.726			A, p. 68.
Tchula (artesian)		227	2.2	2	.30	.17	5.6	296	.96	40				D.
Tunica	Tunica	38.1	3.31	1.21	.517	.657	3.79	51.7	[b].426	32.6	1.78			A, p. 81.
Tupelo	Railroad	38.6	4.69	14.8	2.97	5.83	69.5	21.1		9.98	.099			A, p. 26.
Tutwiler (artesian)		104		3.9	15.6	Trace.	12	169		32	.01			D.
Water Valley	Water Valley	6.27	.800	1.32	.650	1.07	4.31	8.07		11.9	.553			A, p. 106.
Do		14		8			7	23		26				D.
Waynesboro	Waynesboro	397	5.94	2.94	.722	1.64	71.7	465		26.5	1.37			A, p. 61.
Ways Bluff	Allison's	89.2	11.8			149	110			98				A, p. 111.
West		16		34	7	17	6	73		12	10			D.
West Point	West Point	35.5	8.01	9.06	2.17	3.16	6.82	63.5		9.78	2.19			A, p. 33.
Do	368-foot	121	2.88	11.4	2.17	1.23	75.5	487		7.68	.998			Do.
Wortham (artesian; 786 feet deep).		69	Trace.	29	2.3	18	8.2	132		27	3.1	7.6		G.
Yazoo	Main street	141	2.24	.787	.455	1.58	5.90	1.82	[a]1.79	19.4	2.44			A, p. 97.
Do	Waterworks	62.3	5.30	10.7	3.61	12.9	7.58	95.7	[a]1.15	231	16			Do.
Do	A. M. Kolm's	533	22.2	561	459	3160	570	240		23.8	([c])	9.96		A, p. 98.

[a] Phosphoric acid is taken as P_2O_5. [b] Iron bicarbonate is taken as $FeH_2(CO_3)_2$. [c] Iron carbonate is taken as $FeCO_3$.

SPRING WATERS.

Locality.	Name of spring.	Sodium (Na).	Potassium (K).	Calcium (Ca).	Magnesium. (Mg)	Sulphate radial (SO_4).	Chlorine (Cl).	Carbonate radical (CO_3).	Phosphate radical (PO_4).	Silica (SiO_2).	Iron and alumina (Fe_2O_3+ Al_2O_3).	Iron (Fe).	Aluminum (Al)	Lithium (Li).	Organic matter.	Authority.[a]
Meridian	Arundel[b]	13.4	.....	1.9	0.40	3.3	4.9	15	.....	.....	.....	.....	.....	.....	.....	H.
Baldwyn	Baldwyn	4.12	4.61	3.35	1.37	7.76	2.48	10.4	.....	17.6	.....	5.93	.....	.....	.....	A,p.25.
Hazelhurst	Brown Well No. 3	80	69	188	71	935	65	147	.....	23	.....	93	11	.....	11	B.
Do	Brown Well No. 4	49	16	250	92	1106	45	117	.....	21	.....	37	29	.....	8.2	Do.
Do	Brown Well No. 5	53	15	142	67	425	79	214	.....	40	.....	22	12	0.15	8.6	Do.
Do	Lowe's Well	[c]265	21	146	84	745	433	62	.....	48	.....	2.2	13	.....	.....	Do.
Blue Mountain	Blue Mountain	.76	1.4	3.8	6.4	4.4	1.2	21	.....	11	.....	.41	.....	.....	3.9	I.
Durant	Castalian Springs	65	79	188	52	855	26	.....	.....	126	83	.....	.....	.....	.....	J.
Raymond	Cooper's Well	121	4.7	162	96	936	131	.....	.....	.....	58	.....	17	.....	.....	K.
Weems	Donald No. 2	12	2.4	63	2.4	13	7.5	101	.....	12	.....	1.5	.....	.....	.....	H.
Do	Mineral Springs No. 1.	4.1	.65	102	3.8	13	9.1	154	.....	13	.....	.98	.....	.....	.....	Do.
Caledonia	Kolola South Spring.	1.7	4	6.7	2.8	3.6	5.6	35	1.9	9	.....	10	.....	.....	.....	F.
Do	Kolola North Spring.	2.2	3.3	6.6	2.0	5.2	5	34	1.9	6.7	.....	9.9	.....	.....	.....	Do.
Mammoth Springs	Mammoth Mineral Springs.	6	.68	12	2.4	2.2	7.8	24	.....	19	.....	.....	.....	.....	5.8	Do.
Bay St. Louis	Park Mineral Springs.	16	1.1	5.6	2.7	5	13	31	.....	19	.....	3.8	.....	.....	.....	L.
Springs	Pierce Springs	86	.....	93	42	14	15	365	.....	36	.....	13	.....	.....	.....	M.
Robinson Springs	Robinson Springs.	95	17	38	30	178	188	7	.....	39	.....	3.2	.....	.....	.....	F.
Vossburg	Stafford Springs	9.5	7.6	101	4.7	12	10	159	.....	34	.....	1.3	.....	.....	.....	B.
Quitman	S.H.Terrell Spring	46.6	3.73	49.3	2.64	6.49	5.88	328	.....	32.8	1.4	.....	.....	.....	.....	A,p.59.

[a] H=R. W. Jones, University of Mississippi. I=William Krauss, Memphis, Tenn. J=L. G. Patterson, Agricultural and Mechanical College of Mississippi. K=J Lawrence Smith. L=W. F Hand, Agricultural and Mechanical College of Mississippi. M=R. W. Jones, University of Mississippi. For other references see footnote to table of deep wells, above.

[b] Hardiness=18.75.

[c] Sodium crenate=5.96.

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